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The following Anaconda alloys are those most widely used for tube sheets and baffle plates.

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Naval Brass-450 is an alloy of the same general type as Leaded Muntz Metal but includes approximately 0.75% tin in its composition. The tin content increases the alloy's resistance to corrosion, and makes it preferable to Leaded Muntz Metal, especially at higher than normal working temperatures.

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Ambraloy-917 is available for use where strength and corrosion resistance superior to Naval Brass and Admiralty Metal are desired, as in oil-cooler tube sheets.

Cupro Nickel, 10%-755 and Cupro Nickel, 30%-702 are used extensively with tubes of similar composition in marine condensers and in process heat exchange equipment.

Baffle and Support Plates for use in oil refinery equipment are most often of Leaded Muntz Metal and Yellow Brass. For more severe applications Admiralty, Naval Brass, Cupro Nickel, Copper, or Everdur® are often used.

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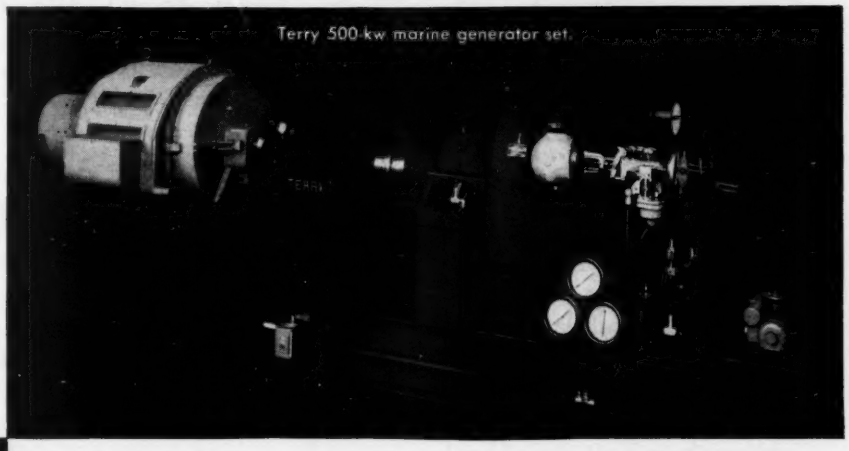

Terry 500-kw marine generator set.

Terry solid-wheel turbine with upper half of casing removed.

Dependable, compact, efficient . . . Terry marine turbines are specially designed for driving generators, boiler-feed pumps, fuel-oil pumps, compressors, etc., aboard ship. They are the result of over fifty years of experience in designing equipment for commercial and naval vessels.

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A reproduction suitable for framing of this highly original drawing by Marie Tuiccillo Kelly is available. Write United States Steel, Room 2801, 525 William Penn Place, Pittsburgh 30, Pa.

U. S. Navy photograph of artist's concept of the nuclear-powered, guided-missile cruiser under construction at Bethlehem's Quincy shipyard.

Keel for the cruiser was laid in a huge, new building basin Dec. 2, 1957.

First Nuclear Surface Warship

Now being constructed by Bethlehem's Quincy, Mass., shipyard, is the guided-missile cruiser *USS Long Beach*, the U. S. Navy's first nuclear-powered surface warship. A Bethlehem design, this historic craft is scheduled for 1960 delivery. She will displace about 14,000 tons and exceed 700 feet in length.

Under a contract with the Atomic Energy Commission, Bethlehem also is developing a nuclear-power plant for a smaller surface warship. More recently, Bethlehem was awarded a U. S. Navy contract extending this work to a nuclear-powered frigate, the first of her class.

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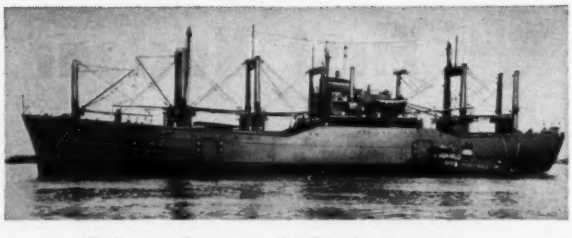
U. S. Navy photo; MK47 tank rolls easily and quickly from dock into port bow of USNS Comet.

B&W Boilers Power MSTS' First Roll-On Roll-Off Vehicle Ship

Designed to transport one sixth of the vehicles attached to an armored division, the USNS Comet sailed on her maiden voyage early this year carrying 378 vehicles from Philadelphia to France. The prototype of its class, the Comet is equipped with 4 hydraulically operated side ramps which may be lowered to dock level to permit the loading of vehicles under their own power. Loading time for the new MSTS ship on its initial voyage was only ten hours, considerably less than would have been consumed if the ship had been loaded by conventional means.

In addition to the side ramps, the Comet is equipped with a stern ramp that is much like the familiar bow of a landing craft and is also used for self-powered loading. Once aboard, vehicles are driven to their assigned places via spiral interior



ramps. When adequate dockside facilities are not available, the ship can be loaded and unloaded through either side or stern ports onto barges. Besides fast loading time, and shorter turnabout time between ports inherent in the new method, other cost-saving advantages include elimination of the need for dockside and floating cranes as well as the ability to lift cargo in trailer trucks without breaking bulk.

The Babcock & Wilcox Company, whose boilers supply power to the new "Comet", U.S.S. Saratoga, the U.S.S. Forrestal, and so many thousands of other American ships, is continuing to work in the tradition of engineering excellence which has made the U. S. A. the world's leader in the design and construction of merchant and naval vessels.

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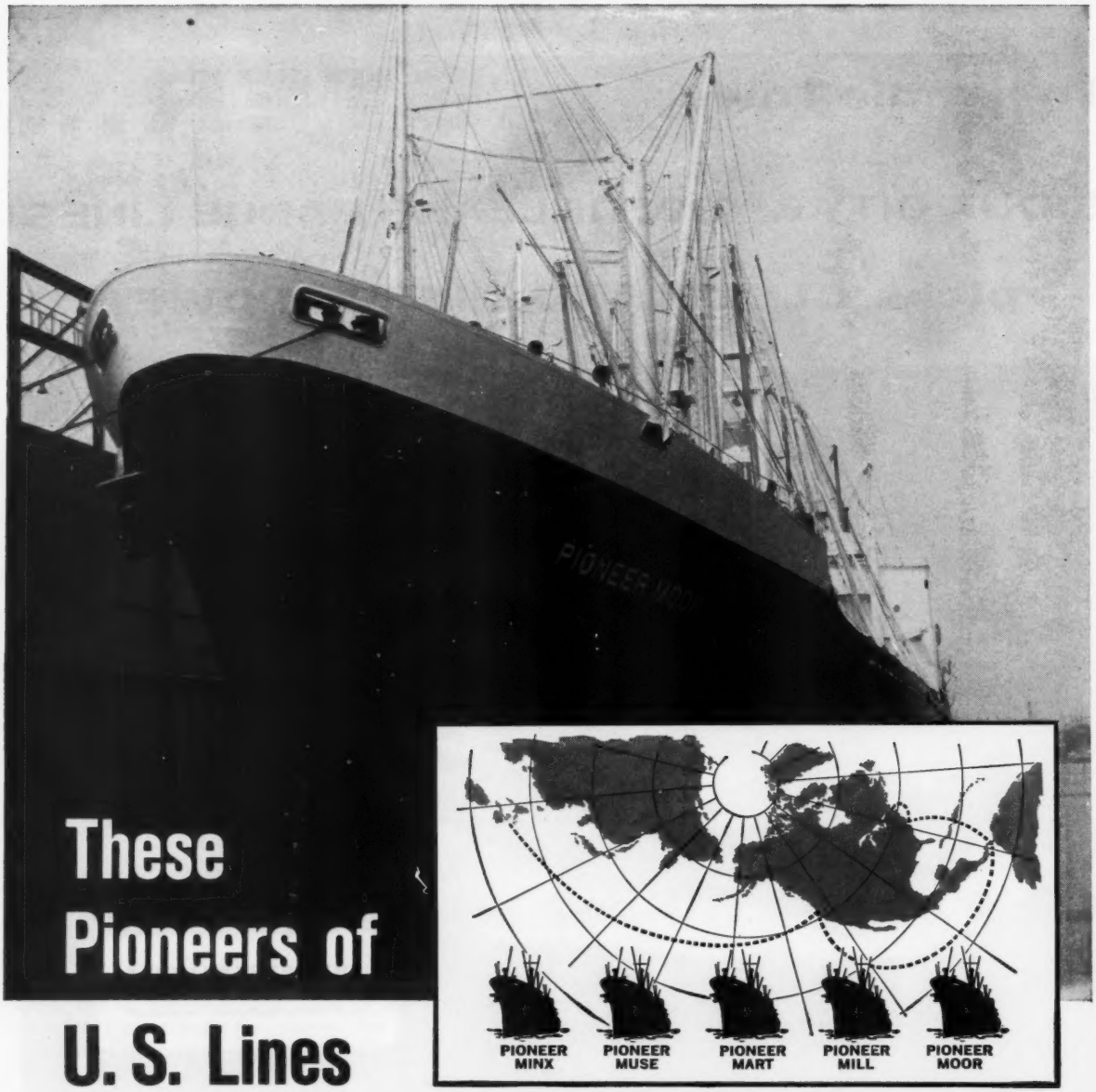

These Pioneers of U. S. Lines provide fast service to the Far East

The United States Lines Company's Pioneer Line ships have established some exceptionally fast runs in their service between the U.S.A. East Coast and Far Eastern ports.

The 20-knot Mariner-Class vessels have reduced former schedules over these routes by many days. The Pioneer Minx, for example made a record run of 28 days from New York to Manila – including a stop at Charleston. The Pioneer Mart, making no stops, made the trip in 26 days. The combination of time saving and increased cargo and reefer space offered by the "Pioneer" ships has created a growing demand for their services among United States Lines customers.

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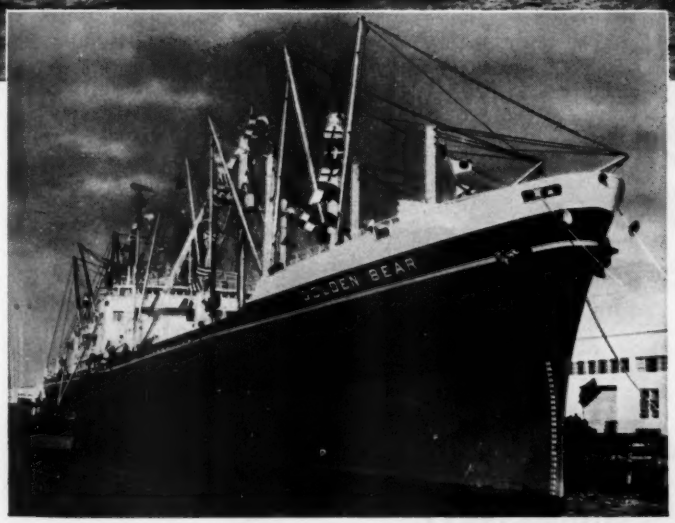

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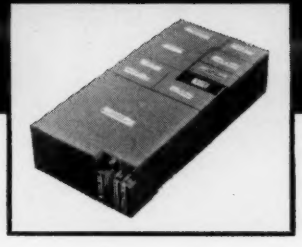

NAVTAC: "Pipeline" to a happy landing

The uniqueness of the new NAVTAC en route navigation and instrument landing system by Stromberg-Carlson is in its *combination* of functional modules.

The NAVTAC equipment is an assembly designed to provide high-performance aircraft with the TACAN navigational aid, plus marker beacon receiver, glide slope and runway localizer for instrument landing situations.

The entire system is packaged in a compact unit only 5" high, 10½" wide, 22" deep, and weighing only 47.5 lbs. Individual modules can be separated up to distances of several feet without any adverse effect on performance.

The equipment is designed to meet the rigorous environment of the high-performance aircraft of today and tomorrow. Its operating ambient temperature range is −60 to +125 degrees C. at altitudes up to 70,000 feet. Widespread use of semiconductors in the ILS receivers and TACAN circuitry means high reliability, small size and low power consumption.

Included in the design is the capability of performing complete preflight confidence tests with the use of a small auxiliary test set.

Complete technical details on the NAVTAC system are available on request.

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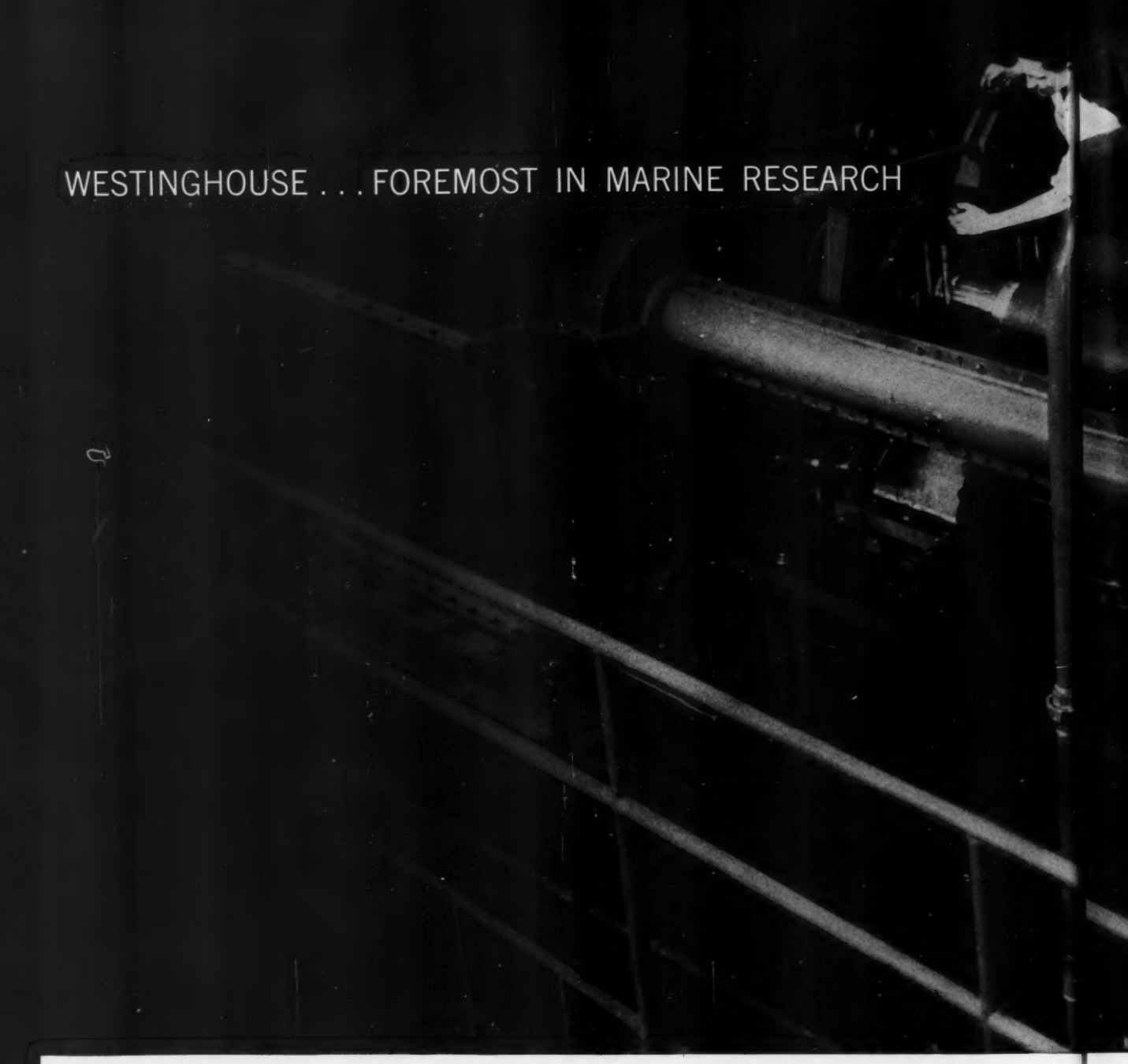

Advanced Gear Designs

From Westinghouse Research

Westinghouse uses this full-scale, first-reduction, locked-train propulsion gear to improve gear design. On it, tests which cannot be made on installed units are performed to determine actual durability of parts and to produce faster, greater, more significant improvements in gear design.

To build better marine reduction gears, Westinghouse makes every imaginable test, including: effect of load and speed on gear wear and noise; effect of rapid speed changes; modulus of elasticity of possible new gear metals; effect of manufacturing tolerances and operational wear. At gear roots, strains are checked electronically to yield data for stress calculations in gear design and for the best arrangement and type of gear and bearing lubrication.

All this testing enables Westinghouse to design and manufacture quieter, more efficient and more reliable gears for the marine industry. This is only one example of the kind of research constantly in progress at Westinghouse, where better, longer lasting marine propulsion and auxiliary equipment is being designed and built.

Take advantage of the results of this research, which are apparent in low-maintenance marine equipment. Contact your Westinghouse sales engineer, or write: Westinghouse Electric Corporation, 3 Gateway Center, P. O. Box 868, Pittsburgh 30, Pa.

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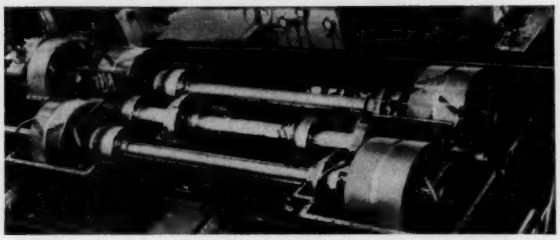
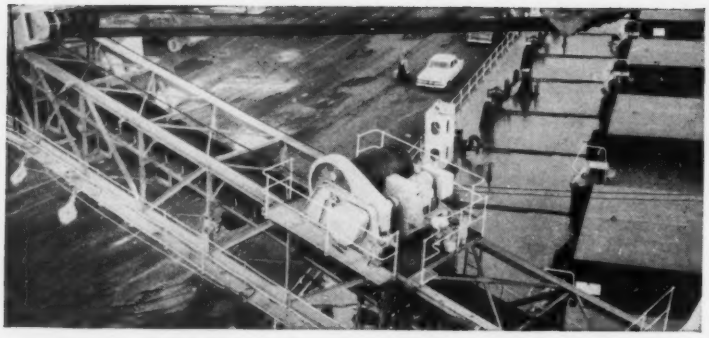


LOCKED-TRAIN GEAR TEST of full-scale, first-reduction gear trains, the size installed on aircraft carriers. Speed and torque can be changed at will. Misalignment can be investigated with respect to tooth loading and bearing wear.

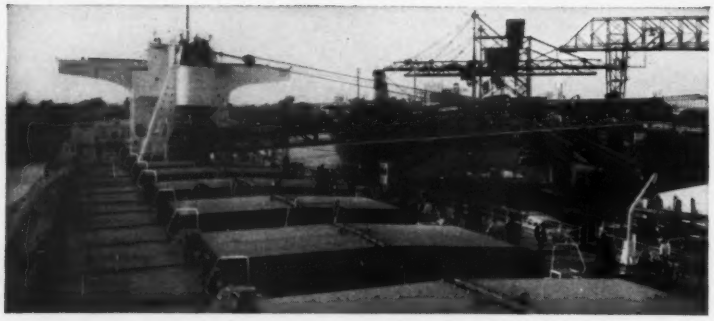
YOU CAN BE SURE...IF IT'S **Westinghouse**



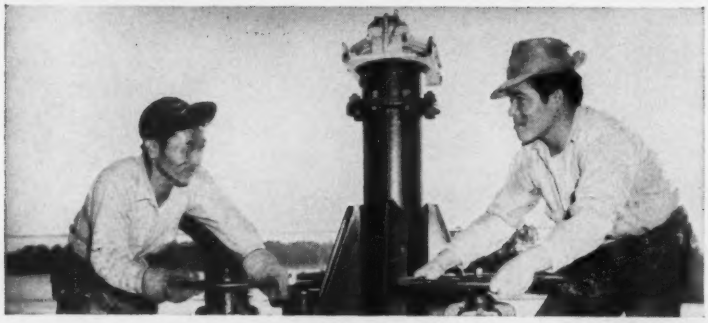
Saves in handling ore: Automatic unloaders carry ore off NBC ships. Monel* alloy pins keep sheaves running free. And Monel ALEMITE® grease fittings in the pins lubricate moving parts. Inside the holds, the gates that control the flow of ore swing on Monel hinge pins.

National Bulk Carriers states

"Monel—a proven money-saver in every division of our ships"



Saves on deck: Large Monel alloy nuts and bolts secure hatches on many NBC ships. Why Monel alloy? Because these fastenings resist marine corrosion ...don't "freeze up." NBC finds Seagoin'* Monel alloy the best material for parts exposed to salt-air and salt-spray corrosion.



Saves in handling oil: The topside sections of reach rods that control flow of oil on tankers are Monel nickel-copper alloy. Shafts and shaft sleeves in fire pump, main and auxiliary circulating pumps, ballast pump and many other pumps subject to salt water and other corrosive material and severe wear are also Monel alloy. NBC finds that *rugged Monel shafting and sleeves last very much longer.*

Saves in ship-handling: Here's S.S. Ore-Convey's anchor windlass. Its smaller shafts are Monel alloy. Its guide blocks and several of its lubricating fittings, too. *The wear resistance of Monel alloy greatly adds to part life.* In NBC tugs, propeller shafts are Monel alloy.

And below decks: National Bulk Carriers standardizes on long-lasting grease fittings of Monel nickel-copper alloy. In feedwater heaters . . . in salt water evaporators . . . valve stems . . . valve trim and in many other engine room services . . . Monel alloy outperforms other metals.

When you need a strong, corrosion-resistant metal to give long, trouble-free service at sea, choose Seagoin' Monel alloy.

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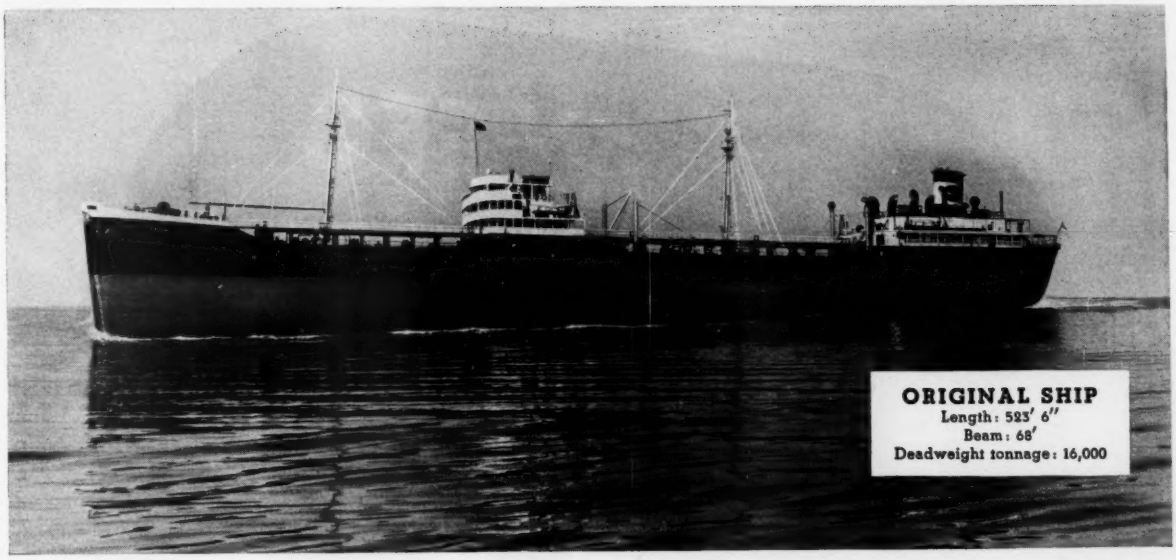
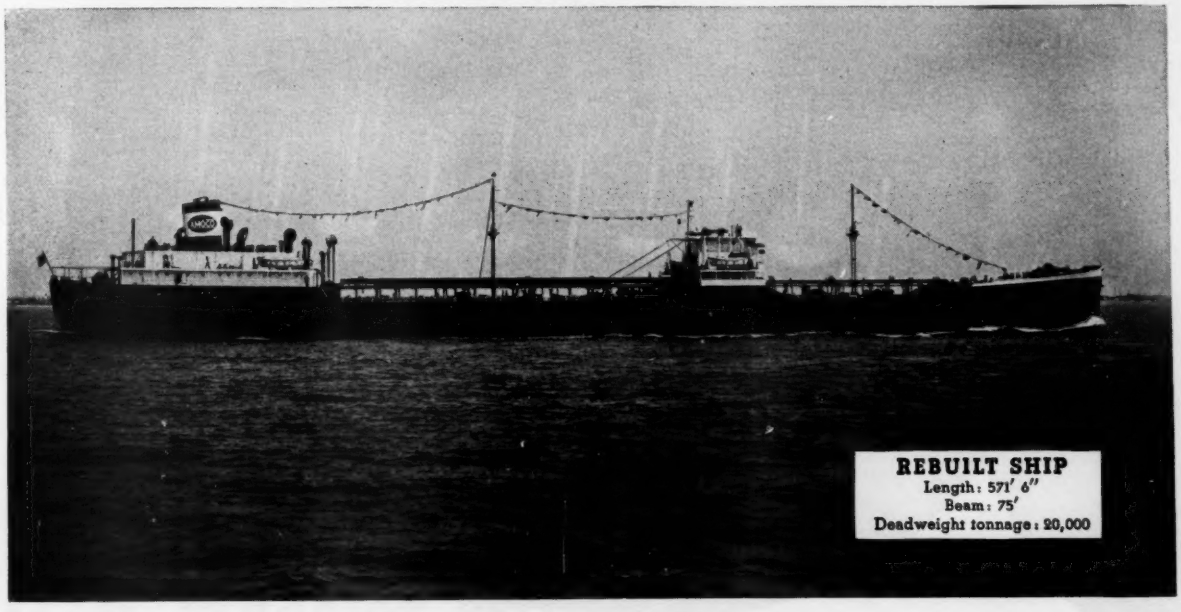


NEWPORT NEWS "JUMBOIZES" WARTIME T-2 TANKER



READ WHAT NEWPORT NEWS IS DOING TO HELP OVERCOME TANKER OBSOLESCENCE

The Amoco Delaware is one of four T-2 tankers to undergo a unique "jumboizing" operation at the Newport News Yard. That required only 42 working days.

Along with other alterations, her cargo tanks were completely replaced with a longer section of wider beam. Three more of these 310-foot sections are building at Newport News to complete conversion of additional tankers.

Enlargement of the DELAWARE, according to Vern Drew, Amoco's General Manager of Marine Operations, resulted in no appreciable loss of speed with the increase in capacity from 16,700 to 20,000 deadweight tons.

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Operation Jumbo is another example of the "tough" ones at Newport News. And for good reason. Newport News has the fully integrated facilities and the skilled personnel to turn out extensive conversions and alterations in the shortest possible time.

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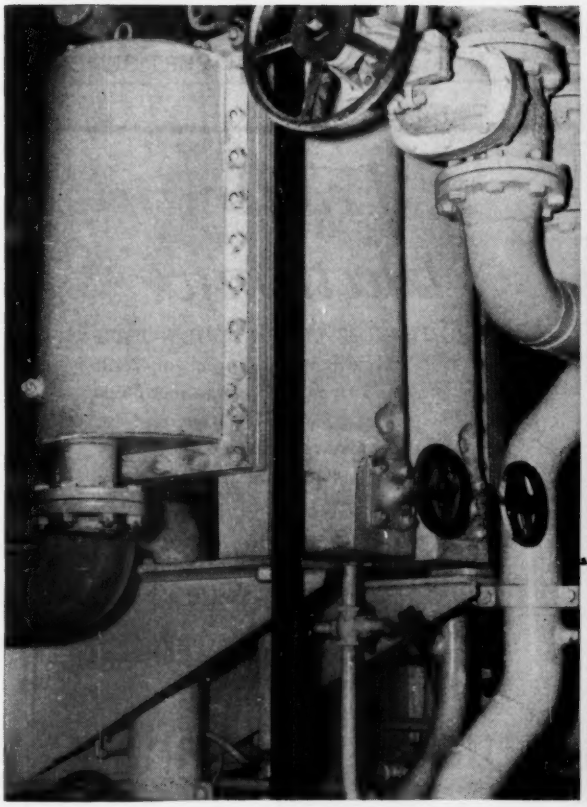
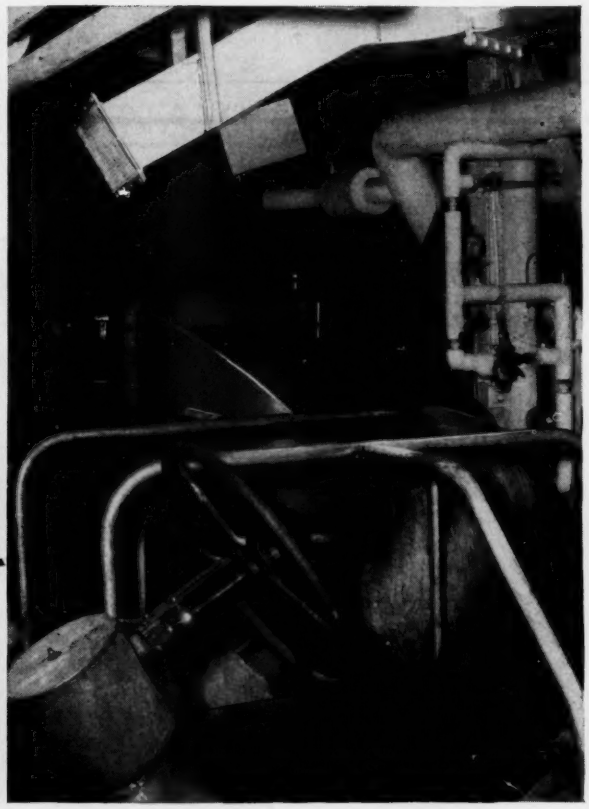


Compact design and ready accessibility of C. H. Wheeler Twin-Element, Two-Stage "Tubejet" Air Ejectors contribute to efficient machinery arrangement in the U.S.N.S. Comet.



Two C. H. Wheeler Condensers, hung from 6000 hp GE turbines, were designed to turbine requirements. They give minimum condensate depression and effective steam distribution.

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Next time you're planning on marine condensers check on C. H. Wheeler's lightweight, compact design. Find out about "Tubejet" Steam Jet Air Ejectors, with integral piping and valving, too.

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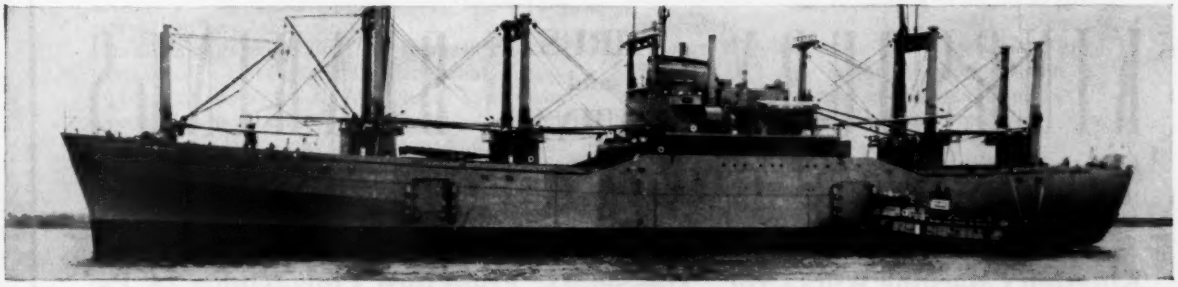

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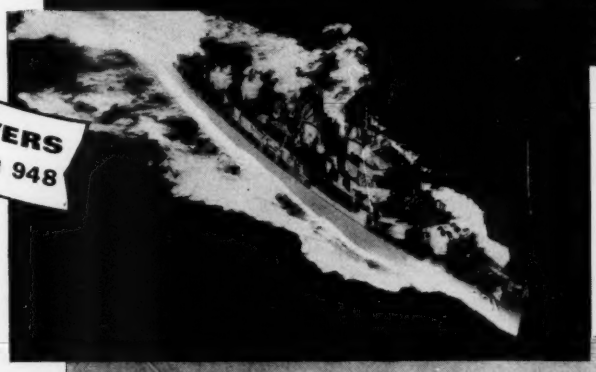

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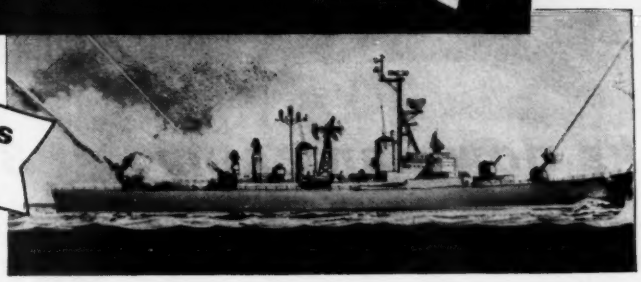

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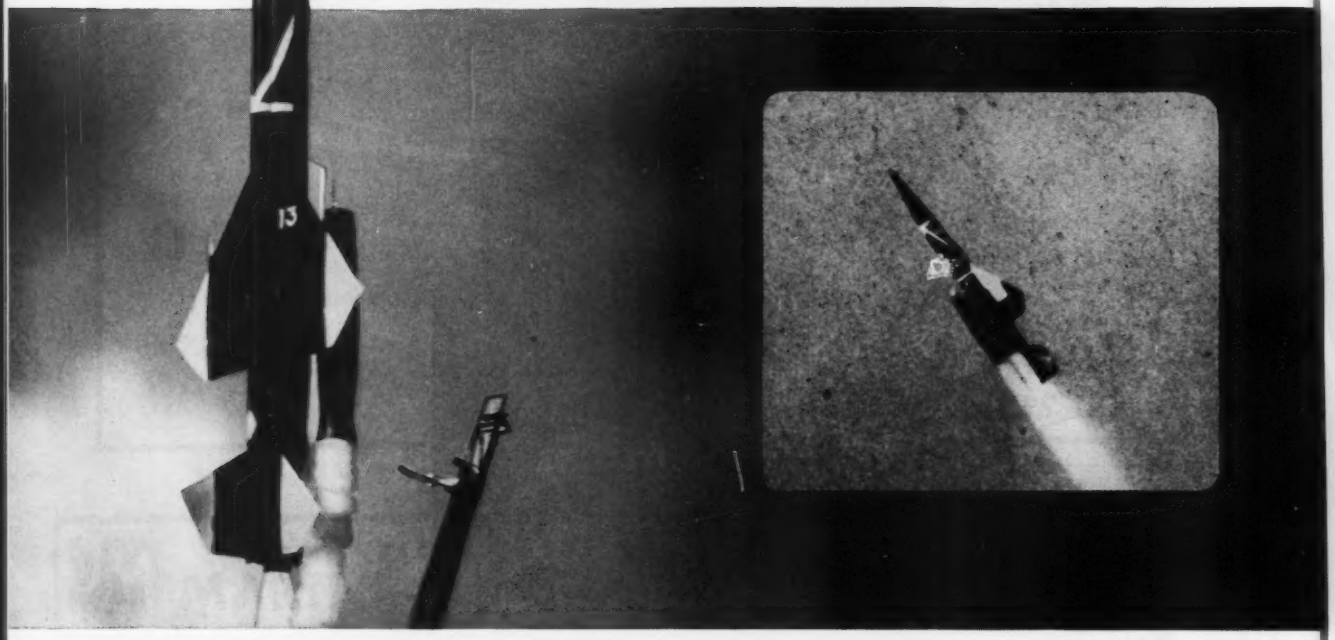

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It tracks down an enemy at 300 miles

Described as the most potent of all ground-to-air defense missiles, the Bomarc pilotless interceptor, designed by Boeing, stands poised for the destruction of any "enemy" bomber within a 200-300 mile range. Its booster rocket has the power to hurl it more than 60,000 feet straight up; then, powered by two ramjet engines, it hurtles by electronic instinct to its target at up to 3 times the speed of sound. For this guardian of our homes and way of life, RCA has been privileged to supply important advance components of the guidance system.

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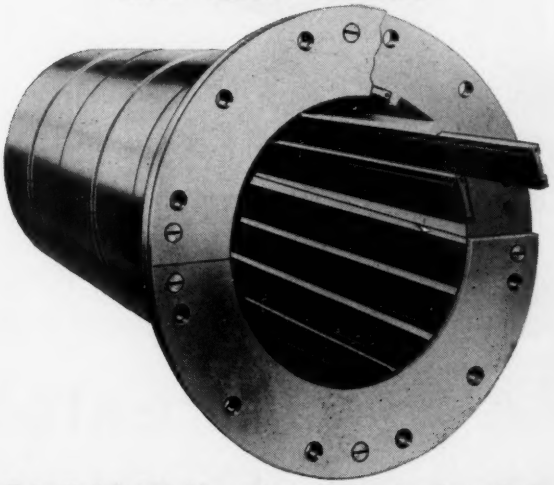

Soft rubber bearing surface—efficiently lubricated by water—this bearing far outlasts all hard surface types, protects propeller shafts, reduces vibration. More than pays for itself in extra wear alone. Saves you time, trouble, and upkeep expense.

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Furthermore, Yale Rail Kings—ideal for moving materials in a production line at a steady pace—can pull a string of loaded trolleys easily because a spring-loaded, rubber-tired wheel provides plenty of traction. This wheel rolls against the underside of the track, thus assuring efficient operation on standard I-beams as well as special rolled tracks.

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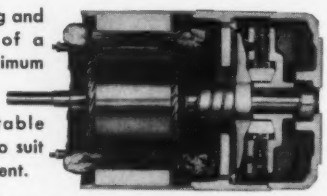

- Permits inching and positioning of a load with maximum safety.
- Gives adjustable acceleration to suit load requirement.
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Journal of the AMERICAN SOCIETY of NAVAL ENGINEERS, Inc.

VOLUME 70 MAY, 1958 NUMBER 2

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SECRETARY'S NOTES

The Annual Banquet

In its 70 years the Society has had 40 Annual Banquets. This year's, the 40th, was in many ways one of the most successful. It was not the largest by a considerable number. Attendance fell about 5 per cent below that of 1957. We interpret this as tangible evidence that there is a recession abroad in the land and that the effects of this are touching the members and friends of the Society. Peculiarly, however, membership is increasing at a healthy rate in spite of the increase in dues which was effective this year. One possible answer which occurs to us is that the banquet is a luxury and the JOURNAL and membership in the Society are becoming a necessity.

Certainly these words describe what we have always attempted. The Council and the Banquet Committee made every effort to assure that the 1958 Banquet was luxurious and we believe, without reservation, that they were successful. This was after an initial decision to practice austerity which was set aside when it became apparent that the scare psychology was not helping to offset the reccessionary effects which seemed to be snowballing in the country. Certainly a Society with such viable membership as ours should follow the course which indicates positive optimism in regard to the country's economic future.

As is customary, the President, Rear Admiral Leroy V. Honsinger, U.S. Navy, presided over the banquet. Before the excellent viands provided by

our host hotel were served, invocation was pronounced by Captain J. D. Zimmerman, Chaplain Corps, U.S. Navy. In the usual reverse method, after all appetites were satiated and the physical lassitude which such exercises foster were well established, the more serious part of the program which has to do with stimulation of the mind, followed.

The President in his welcoming speech explained the Society and its aims in a very refreshing manner, after which he turned the meeting over to the toastmaster who proceeded to introduce those at the speaker's table and the principal speaker.

Seated at the Speaker's Table were: Vice Admiral Harold G. Bowen, U.S.N., Retired, President, 1938; Rear Admiral Henry Williams, U.S.N., Retired, President, 1940; Vice Admiral Earle W. Mills, U.S.N., Retired, President, 1945; Rear Admiral Harvey F. Johnson, U.S.C.G., Retired, President, 1946, 1948; Rear Admiral T. A. Solberg, U.S.N., Retired, President, 1949; Rear Admiral E. W. Sylvester, U.S.N., Retired, President, 1954; Rear Admiral Kenneth K. Cowart, U.S.C.G., President, 1956; Rear Admiral A. G. Mumma, U.S.N., President, 1957; Rear Admiral Leroy V. Honsinger, U.S.N., President, 1958; The Honorable W. J. McNeil, Assistant Secretary of Defense; Vice Admiral Ralph E. Wilson, U.S.N., Deputy Chief of Naval Operations, Logistics; Rear Admiral Harold D. Baker, U.S.N., Commandant Potomac River Naval Command; Captain H. C. Dinger, U.S.N., Retired, Secretary-Treasurer, 1908-1910; Captain Fred C. Walton, U.S.N., Retired, Secretary-Treasurer, 1945-1948; Mr. Walter Green, President, The Society of Naval Architects and Marine Engineers; Captain W. N. Landers, U.S.N., Retired, Secretary. The Society of Naval Architects and Marine Engineers; Mr. Donald L. Herr, Honorary Member, Prize Essayist; Mr. Arthur G. Fessenden, Honorary Member; Captain J. D. Zimmerman, (ChC), U.S.N., Senior Chaplain, Potomac River Naval Command; Mr. J. W. Fauquier, representing the Statler-Hilton Hotel.

The principal address, which as those of us who attend our banquets know, either makes or mars the entire affair, *made* this one. Vice Admiral Earle W. Mills, U.S. Navy, Retired, a Past President of our Society; a past Engineer-in-Chief of the U.S. Navy; a Past President of our sister Society, the Society of Naval Architects and Marine Engineers; a Past Coordinator of Ship Building and Repair of the United States; a Past Chief of the Bureau of Ships and currently Chairman of the Board and President of Foster Wheeler Corporation, a dynamic speaker and a very worthy citizen, made this principal speech and those who did not hear him may read his words on page 187 of this JOURNAL. His subject "Engineering and Education" is one in which this country has been most severely castigated by its own intelligentsia in science and engineering. Our speaker, however, brought the subject down to earth and presented it in its true light from the old fash-

Vice Admiral Earle W. Mills, U. S. Navy, Retired
1958 Banquet Speaker

ioned American point of view, so that all who are seriously interested can get their feet on the ground and may join a movement to solve the problem by real American methods instead of insisting on adopting those of the opposition. This was very stimulating in these days when so many seem to feel that the only way to meet a dictator is by means of a dictatorship. That there is still true faith and belief in the real American way of life is quite refreshing.

Council Meetings

The Council met on Thursday, 17 April 1958, to conduct routine business and to consider what action should be taken in regard to the A.S.N.E. Award for 1957. The latter subject is discussed later on.

The following resolution was adopted:

Resolved that upon completion of 50 years of active membership in the Society, any member shall automatically be declared to be a paid up life member.

This action, probably long overdue, immediately makes the following members paid up life members:

Henderson B. Gregory	56 years
W. E. Maccoun	56 years
Alfred W. Johnson	56 years
H. C. Dinger	55 years
J. B. Turner	55 years
W. V. N. Powelson	54 years
Albert Norris	53 years

Austin S. Kibbee	51 years
Ernest H. B. Anderson	50 years
George S. Cairnes	50 years

Since a great deal of time was devoted to the A.S.N.E. Award discussion, other routine business, and it is all quite minor, was held over for later meetings.

The A.S.N.E. Award

In the February 1958 issue of the JOURNAL we published the story of the A.S.N.E. Award. We did as much as seemed possible to bring the award to the attention of the membership with the hope that making an award for 1957 would be feasible.

A committee consisting of three Past Presidents was appointed to consider citations which might be received and to assist the Council by making a recommendation of its opinion as to the outstanding achievement which was cited.

To orient its work the Committee devised and submitted to the Council a proposed definition of "Naval Engineering," which it presented with the following words:

Before undertaking an examination of the citations for the various candidates and with particular consideration of the fact that 1957 will be the first year for which the A.S.N.E. award will have been made, your committee considered it essential, for its purposes, to establish a definition of the term "naval engineering."

Although the initial concept of this profession was largely limited to the design, construction, operation and maintenance of steam power plants and related machinery in naval vessels, a long series of technological developments have greatly broadened the professional outlook and responsibility of the naval engineer. In the propulsion field he has advanced from low pressure reciprocating engines to high pressure steam turbines, gas turbines and internal combustion engines—and in fuels from coal to liquid fuels and nuclear energy—all with their attendant changes in auxiliary machinery. The introduction and use of electricity on board ships brought with it additional apparatus for generation, distribution, lighting, ventilation, refrigeration, power-steering, ship and apparatus control, communications, fire control, navigation and a host of other power and electronic applications.

The wide use of welding techniques both for hull fabrication and machinery emplacement has brought the naval engineer into intimate contact with hull structural problems. Similarly, new discoveries relating to the influence of hull form on propeller inflow and propulsive efficiency have made him just as responsive to hydrodynamics as his professional colleague, the naval architect.

On the basis of these enlarged professional responsibilities—reflected alike in the training and employment of the naval engineer, in the broad range of sciences which have become his every day tools, and in the scope of the articles which fill his journals—the committee has chosen to use the following definition for naval engineering, based on traditional sources, as a general guide in its further studies of the citation of candidates for the 1957 A.S.N.E. award:

> **"Naval engineering is the art and science by which the properties of matter and the sources of energy in nature are made useful to man in the design, construction, operation and maintenance of naval vessels and of their machinery, fittings, equipment and components, including the facilities ashore and afloat, for their support."**

This focused the Council's attention on the point that this criterion (the definition of "Naval Engineering") had been used by the committee *but it had not been available* to the members and officials who had been asked to nominate candidates for the award.

It also pointed up the need for the Society to recognize a definition of its own scope. The Council was very much agreed that the Committee had done an outstanding job in devising the definition but decided that it (the Council) should not act until the full membership had been given an opportunity to comment on its adequacy. It is therefore published above and will reappear in the August issue. Before the end of the year, the Council will agree to and will promulgate an official definition to be used as a criterion for 1958 awards.

Although the Council considered that the proposed definition was excellent, one particular phase of it evoked considerable discussion. This was whether or not the definition should embrace carrier aircraft, shipboard ordnance and ship launched missiles and if so, whether it was reasonable to rely on an interpretation of "equipment" to include these or they should be spelled out specifically. Any comments by members will be greatly appreciated by the Council.

In regard to the citations which were set before it, the Committee had this to say:

As a related matter, it is perhaps pertinent to point out here, that the committee was deeply impressed by the exceptional achievements in the field of naval engineering represented by the citations. Although this made the task of final selection extremely difficult, it was most heartening to the committee, as it undoubtedly is to the Council, to note the very high standard of professional attainments and the broad scope of technological interests revealed by the citations. The committee considers that these citations place the work of the naval engineer of today in a most favorable light.

In accordance with its instructions, the Committee selected a candidate for the A.S.N.E. Award for 1957, whose name was placed before the Council. The Council very definitely had no objection to the proposed candidate nor did it find any fault with the eminence of his contribution, but it was faced with a difficult decision.

The fact that the definition of "Naval Engineering" was not available to those who made nominations has already been mentioned. In addition to this a review of the situation was made with the following results:

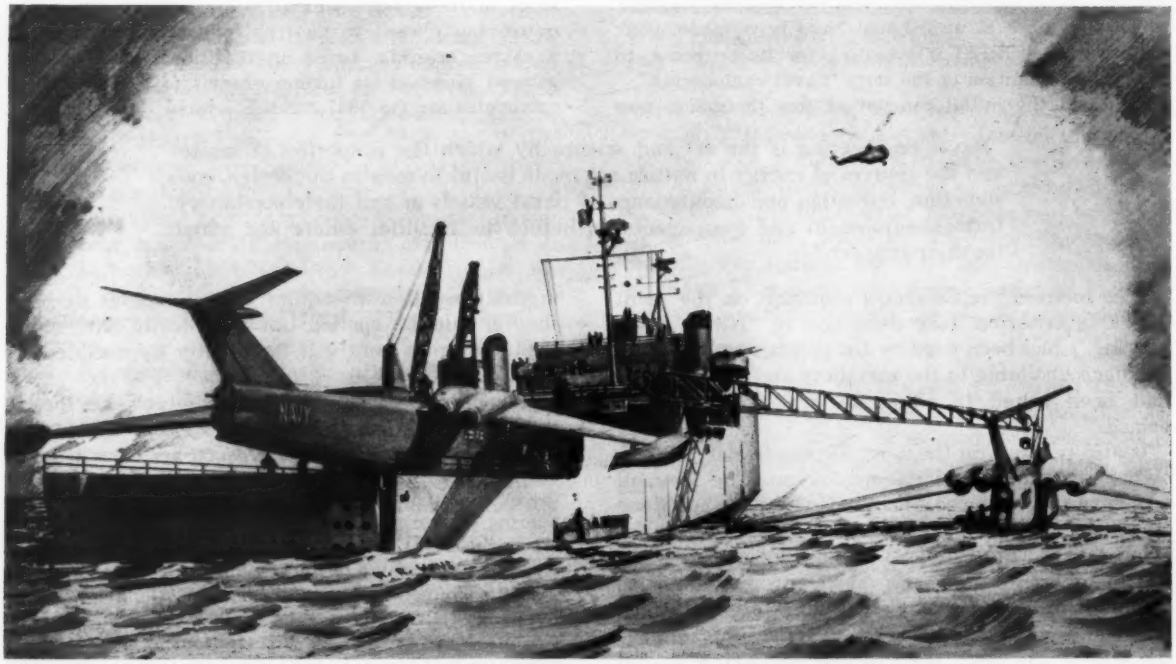
Only one member had acted on the general announcement which was carried in the February 1958 JOURNAL and

A majority of those to whom letters were addressed replied that the newness of the idea and the short time allowed did not permit them to consider the matter with the seriousness which it deserved and therefore could not suggest an awardee for 1957.

With full appreciation of the thorough and painstaking task which the Committee had performed and the unquestioned eminence of the Committee's candidate and of his contribution, the Council reluctantly agreed that it had made an attempt to do a big job too fast and voted that no award for 1957 would be made.

We are sure that this decision will be a disappointment to some. Nonetheless we feel that for an award to be recognized as being of the stature we hope for, it is better to delay and to be reasonably certain than to take precipitate action which might result in a more regrettable misunderstanding.

We do sincerely hope that all members will be on the alert to spot cases of outstanding merit during this year and that the response for 1958 will be so variegated as to source as to give positive assurance that the field was well covered. With this and Society acceptance of a definition of "Naval Engineering," the A.S.N.E. Award launching in the Spring of 1959 should set a precedent which can lead only to glorification of the profession through the years ahead.



Official U. S. Navy Photograph

AV—SEAPLANE TENDER

This ship is designed for the support of large seaplanes. Converted from an LSD hull, it will provide replenishment, repair, and maintenance facilities, including the ability to drydock seaplanes for repairs which cannot be accomplished from the boom location.

VICE ADMIRAL EARLE W. MILLS, U. S. Navy (Retired)

"EDUCATION AND ENGINEERING"

Dinner of the American Society of Naval Engineers, Statler Hotel, May 2, 1958.

Mr. President, Distinguished Guests, and Fellow Members of the Society:

In reading over the address of my predecessor delivered at this dinner last year, "Specialized Manpower," by General Lewis B. Hershey, U.S. Army, I was impressed by several things which he carried out in excellent style, judging by the transcript of his remarks which had been delivered to you "off the cuff." His talk was cleverly humorous, concise, and deeply impressive. In fact, his salutation to "Engineers, real and alleged, and representatives of great corporations who steal engineers from each other," should be made a standard introduction. I shall try to emulate General Hershey with respect to brevity, but I'm afraid that I must refer to my text.

When I decided to speak to you on the subject of Education and Engineering, I made the choice last year before Sputnik I was launched. I deliberately chose a subject so broad that it would be difficult to stray; but I was not keen enough to foresee that this campaign to improve Education in our country would grow to such an extent that I would be caught in the middle of many expert opinions. Of course, I hasten to forswear any expert qualifications in the field, even though I have long been interested as an amateur in both Education and Engineering. I hope that in a simple and homely discussion I may be able to emphasize some points in both areas. Actually, I have very strong feelings that our secondary schools on the whole are not doing a good job in that they do not fill their students with learning or with a desire for learning; any more than our Normal Schools and Schools of Business Administration contribute to true intellectual attainments by their graduates.

To insure that I do not lose my amateur standing, I am making the statement that this social adjustment and progressive type of education has not any more to it than the chemise dress—both have been and are high style, but neither is very satisfying. In fact, I can express it in the form of a recent amusing verse by a Secretary stating her distaste for the new feminine style in a company poll:—

When I don my Easter duds
No sack suit will you see,
For sacks look better filled with spuds
Than they do filled with me.

It is not my purpose to tell you what to do—we have fine educational leaders from the Colleges who are qualified for that—I simply desire to emphasize *how it must* be done and to point out in some degree *why* our Educational standards should be improved.

Most of us are parents and many of us are grandparents. Much that I have to say can well be considered responsibilities from the parental point of view, but the grandparents cannot be neglected, because they are usually the ones who want to "ease up" on "the special kind of children" that make them grandparents in the first place. We should make it impossible for a protesting New York teacher who thinks her pupils are coddled to say "of course, they don't learn very much in school, but they are healthy, happy children."

This question of what is wrong with our education started about five or six years ago in an effort to

find out why so many of our high school graduates were not going to college, in the first place, and when they did go, why so many could not enter colleges without additional work, and why so many college freshmen had trouble carrying courses which contained mathematics and sciences? Related subjects, of course, are adequate schools and facilities at the secondary school levels, as well as improved salaries, training, and status for teachers to insure ourselves at the citizen-parent level that these teachers are properly qualified and interested in doing the job we should like to see them do. While we were drifting along arguing the point how we could best improve our educational system, along came Sputnik.

For that event, we owe Russia a debt of gratitude for blasting us out of our complacency and goading us into a painful reappraisal of our educational standards. However, at the outset, I desire to make it clear that I do not want to copy our schools after Russia—in fact, I want nothing to do with Russia in this respect, because our principal problem is the difference between a democratic and a totalitarian state. I am not concerned that the Soviet put a Sputnik in orbit before we did; but I am concerned as to whether our part in the International Geophysical Year required us to blueprint and make known every schedule in our program to the extent that the Soviet could mobilize resources to attain their similar goals at an earlier date, primarily for the propaganda benefits which they could realize. Manifestly, if we had planned a race with them, we would not have started all over again to build a new carrier rocket. I favor the latter method, personally, because it adds to our own store of knowledge; and I cannot get upset when our competition uses a tried military rocket to get his satellite in the air first, because that knowledge benefits us greatly; and I am most pleased that this experience has renewed and stimulated interest in educational improvements long overdue.

Mr. Alexander Korol of the M.I.T. Center for International Studies, in a recent book on "Soviet Education for Science and Technology," devotes about a third of the study to primary and secondary education and the remainder to Soviet higher education. He presents much that is impressive about their system obtained from both Soviet and non-Soviet sources, particularly in their ability to teach large numbers of young people much more about mathematics and science than our youngsters learn or even try to learn over here. But the Soviets have their troubles too, and Mr. Korol mentions overloading of teachers and their underpayment (both of which sound familiar), an uneven quality in their educational system, a fantastic emphasis on engineering training, and the same silly percentage system, that we insist on at times, which forces teachers to promote pupils who have not really mastered work in a given grade or area.

Mr. Korol's work sets forth clearly fundamental differences between our two societies in education, and they may be summed up in the issue of Freedom versus Compulsion. He says, "The locus of the threat against us is not Soviet education but Soviet communism." We must not miss the point that the Soviet institutional framework is well organized to assure that, first, the largest fraction of the able people goes into science and engineering as professions and that, second, the energies of those able people are directed toward the goals which Mr. Khrushchev and his crew consider most important. The understanding that we must draw from these parallels is that we cannot meet the Soviet challenge successfully, if we continue to do business "as usual," either in education or other major fields. There are certain requirements which must be played ahead of any individual desires, and we must mobilize our society, including education, to assure that our best abilities are devoted to the principles upon which our freedom depends. The threat of communism will be greatly reduced if free peoples everywhere vigorously develop their highest social standards and maintain in a combined sense their moral as well as their technological and scientific superiorities.

Army Secretary Brucker expressed it in fine language for us last month when he said "Our national power lies in moral stamina and stability, hard resolution, unswerving determination and the willingness to place the best interests of America above every other consideration."

What then has happened to our educational system that causes us to raise such a clamor and to fear that it is not meeting our basic needs? The answer is relatively simple but general acceptance of it has been slow in coming until a crisis situation was generated by the Sputnik developments. The answer is that in large part our educational system has "gone soft" in standards, curricula, discipline, management and teaching methods. And worst of all, this softening has taken place through the misguided efforts of a group of so-called "progressive" educators combined until recently with a growing abdication of interest in school welfare and excellence by Mr. John Citizen at local levels. Mr. John Citizen, my fellow members, is you and the likes of all of us throughout most of our land. That is a severe indictment with only one saving grace—there are still a few areas and school districts which have maintained their interest to the extent that these communities have schools far above the national average, thus showing that our general conditions of low educational standards in our secondary schools are due either to lethargy in our local communities, or the inability of our responsible adults to appreciate what constitutes proper educational standards. I suspect that a combination of the two conditions is responsible; and if we *can recognize* our faults it is possible to improve our standards,

slowly at first, and with increasing tempo. We did not get into this situation all at once, and we are not going to correct it overnight.

With respect to the general ability of our responsible adults at local levels to appreciate proper educational standards, I should like to refer to several thought provoking paragraphs from "The Organization Man" by William H. Whyte, Jr., who spent some three years of research and study to trace long-range shifts which organization life is causing in the personal values of our countrymen. Concerning the author. I noted that he graduated from Princeton in 1939; but I was greatly intrigued and pleased to realize that he ascribed part of his education to duty in the U. S. Marine Corps at Guadalcanal. Mr. Whyte raised the question whether the trend to disparage intellectual achievements will be more powerful than the counter-trend to improve the standards of our educational system? Having otherwise described Normal Schools, Schools of Business Administration, and Vocationalists as non-intellectual groups, if not at times actually anti-intellectual in their material atmosphere, he reasons that by default such sectors of education have been allowed to usurp the word "democratic" as a justification for devaluating the curriculum in our educational system; and while liberal arts exponents, or even technological boosters, may win arguments on this score, we may well wonder whether the "so-called anti-intellectual influences" have won the war some time ago. Once the uneducated could have the humility of ignorance: but Mr. Whyte points out that now in some cases they are given degrees and put in charge. This delusion of learning will produce consequences more critical than the absence of it.

Looking down the road a generation or more, those who will be in control of a large part of our educational system will themselves be products of the vocational and social-adjustment type of schooling so widely developed. It does not appear likely, moreover, if the present system is allowed to continue, that the average layman or the great group of local-level parents will be out of sympathy with the vocationalists, because by that time they will know of no other standards by which to evaluate education of their children other than by the limits of their own life adjustment training—or lack of it. Also who will be sitting on the Boards of Trustees, and who will be picking the schools to endow? "More and more, it will be the Organization Man," says Mr. Whyte, "the graduate of the business school —the 'modern man,' in sum, that his education was so effectively designed to bring about."

I hope Mr. Whyte is not correct in his provoking thought and forecast; but the idea is logical and we can insure against such a situation developing only by starting an irresistible demand for better education for our children now and continuing that pressure until the job is finished.

Our low standards have been described by some writers as having produced schools in which no serious learning is going on. It has also been stated that action to improve the educational systems must be preceded by an honest recognition and appreciation of what these faults are. When you have a situation of good school facilities with little learning in them, it is certain that you have a community which is going along with the set-up either because of approval or apathy. I think it is completely true that school districts throughout this country are getting just what they are willing to put up with in the way of schools, and thus we have many schools below acceptable educational standards. Children are not interested and are not encouraged to work hard; there are too many "soft" elective courses which may be substituted for hard training in mathematics and the natural sciences, and thus children do not learn either how to study or to reason logically; and teacher training at the normal schools is filled with too many "tricks of progressive education" and "too much methodology," to quote a prominent educator, to the exclusion of any real consideration for the subjects taught. Last but not least, our public schools do not develop any popular recognition for intellectual achievement, nor do parental and home influences in general stimulate any such desire.

In the last twenty-five years of unbelieveable technological developments and progress we have, in a way, passed through the involved processes of mass production to the even more complicated requirements of automation. On the other hand, both mass production and automation are so new and so few people really understand them that we have little more than scratched their tremendous potentialities. At the same time, we have had impressed upon our field of knowledge the whole new science of nuclear energy involving the widest principles of physics, chemistry, and metallurgy, to say nothing of the greatly accelerated production of guided missiles of all types. To cap this off in my own case, while already reeling from the above considerations, I went to Chicago recently for the privilege of introducing a speaker on the subject of "Atomic Policy in the Space Age."

You cannot hear the above recital of developments without realizing that the demand for engineers in their broadest sense will increase greatly over the long pull. But what I want more than all are well-educated citizens as well as excellent engineers. For those men who desire to enter enginering as a profession, I strongly recommend a liberal sprinkling of the humanities in the engineering education—about 25% at least of the total course—to produce a better educated and well rounded man, most thoroughly grounded in fundamentals as opposed to vocational education. Our determination to improve our educational standards in both the humanities and technical fields and to stimulate a desire and a respect for true learning will help to fulfill our ever urgent need for engineers of imagination and originality.

This whole situation emphasizes the necessity for a steady mature concern to improve our educational

standards at the secondary school levels. This means further that we as parents and grandparents, and as practicing and active engineers, *real and alleged,* can exert considerable influence at our local community levels to improve the situation, particularly if we interest ourselves in the school boards and offer to be of help to them. The amount of mathematics and science courses in our average high schools and other secondary schools should be increased and strengthened as required courses. I believe this should be done regardless of the career to be followed in college, or whether the student goes to college; simply to improve the high school curriculum, increase the educational standards and teach some reasoning and elementary logic. The quality of scholastic achievement should be increased and an appreciation for intellectual attainments must be developed both in the parents and in the children.

If local citizens, such as ourselves, become interested to the point that they demand improved facilities and broader basic curricula for their children the school boards will provide them and will also find the faculty that can teach such worth-while subjects. What we really want and demand we will get—if we support it—and it is *our responsibility* starting at the local level.

Only last week in the May *Ladies Home Journal* Dr. Griswold, President of Yale University, made these particularly pertinent remarks:—

"What can we do about it? There is practically no limit to what we can do once we make up our minds it is worth doing. Here is an objective that requires no summit conference with foreign powers, no departure from American tradition, no funds we cannot easily afford and readily provide—in fact, nothing save a clear view of the goal and the courage of *our* conviction that it must and can be attained. Seldom has an objective as vital to the national interest as this been so surely within our reach.

"Unfortunately, most of us get no farther in this direction than damning the schools and waiting for Washington to do something about them. If this attitude prevails, the cause will be lost. Though the Federal Government can help, it is we ourselves in our local communities who must accomplish our educational salvation. I do not say this for traditional reasons—because it always has been so—but bacause in the nature of the case I believe it must be so. In our scheme of things, education is almost as much a matter of individual conscience as religion is. This is as true of its institutions as it is of its students. In the final analysis, both achieve their greatest heights because they wish to, *not* because they are compelled to."

I'm not talking in favor of technical subjects over the humanities, nor am I trying to persuade all high school graduates to become engineers; but I am trying to improve the educational level of our high schools to the extent that a graduate can enter college as a freshman to follow up his chosen career, without having to take "no credit" or "bone-head" courses to make up his entrance requirements. Let's quit entertaining our teen-agers in high school and start teaching them some fundamentals in English, Mathematics, History, Literature, Natural Sciences, Expressive Writing, and even Spelling, and in addition, cultivate in them a desire for learning and how to study.

With all the advances that are to come, when estimated against the giant steps taken in the last quarter century of our progress, I feel that I can close this discussion in no better manner than to quote Allan Nevins, DeWitt Clinton Professor of American History at Columbia University, when he says:—

"We can be certain, too, that the necessity for a cultural and moral growth to arm us to meet change will grow urgently, even ferociously. The voices which counsel us to spend all our energies on science are sinister counsels. Most of our energies must go to development of the intelligence and character which can control science. Even in the short-run necessities of the cold war it is culture in the broadest sense that we need."

"The nation which has the most ideas, the best books, the richest art and music, the deepest sensitiveness, will in the end conquer the nation which impoverishes its mind and soul. H. G. Wells was on firm ground when he said: 'The future is to be a race between Education and Destruction.' It is more than ever such a race; but humanity will win it if it throws enough strength behind education, and interprets that word in the broadest sense.

"Caught as we are in a fateful rivalry with another Great Power which would overthrow our whole system, we must keep our nation symmetrically healthy. Our capacity to make revolutionary decisions in social, cultural and moral fields is just as important as our capacity to make epochal scientific discoveries. Indeed, it is more important, for science is but the handmaiden of our society and culture. It would avail us nothing to gain a nuclear ascendancy and lose our own souls. That is one reason why we must guard against a distortion of our education, our creative activities and our entire way of life in the name of scientific leadership. The most powerful and influential nation a quarter-century hence will not be the one that has met the challenge of science most energetically; it will be the one that has met all the hundred challenges which make for a luminous, well-rounded civilization."

ROBERT TAGGART

EARLY DEVELOPMENTS IN MARINE PROPULSION

THE AUTHOR

formerly Director, Experimental Test Division, Reed Research, Inc., has been recently appointed and promoted to the new position of Technical Administrator. He received his Bachelor of Science degree in Naval Architecture and Marine Engineering from Webb Institute of Naval Architecture in 1942. He served with the Consolidated Steel Corporation, U. S. Maritime Commission, U. S. Army Transportation Corps, and the Navy Department prior to his employment with Reed Research in 1954.

INTRODUCTION

FROM THE EARLIEST hand-paddled log of the cave man to the swift and powerful propeller-driven leviathans of today the history of marine propulsion development has been a fascinating story of invention and experiment, success and failure, triumph and tragedy. The ideal ship propulsion device has not yet been found, but as the inventors of the future work toward the optimum device they can learn much from the trials and tribulations of inventors of the past.

The generation of a propulsive thrust to move a body through the water requires the acceleration of a mass. The first primitive man to swim across a stream exercised a form of self-propulsion in that the motion of his hands and feet accelerated masses of water. Early man's observation of animals conveying themselves downstream on logs and branches probably led to his adoption of a supporting vehicle. It was the ensuing combination of a propelling force with a supporting craft which initiated the development of ship propulsion devices.

As man's knowledge expanded he found new ways to lessen the effort needed for his aquatic transportation. He learned that hollowing out a log reduced the vehicle weight without reducing its buoyancy, thus giving it an increased carrying capacity. Shaping the ends of this hollowed-out log also provided a greater speed for the same amount of energy exerted.

The fundamental inefficiency of hand propulsion led logically to the use of paddles. By this means even primitive man utilized the mechanical advantage of the lever and the greater propelling power of a wide, flat blade. The use of a double-bladed paddle also occurred to him when he found it difficult to maintain a straight course when paddling on one side of his canoe only. As the size of the log canoes increased to accommodate first a family, and then groups of hunters or war parties, the use of multiple paddles was found to give increased speed with the expenditure of less energy per man.

The conversion to oars was probably the result of early man's attempt to ease the strain on his muscles by supporting the paddle on the gunwale of his boat, pinning it with his hand to form a fulcrum for his lever. Finding that this reduced the effort required, the next logical conclusion was that thole pins, or rowlocks, to affix a permanent fulcrum would be advantageous.

The actual transition from paddle to oar is lost in antiquity. However an Egyptian monument, erected somewhere between 2800 and 2000 B.C., contained a bas-relief of a vessel pulling forty oars. The Phoenician ships powered by oar and sail were plying the waters between Sidon, Cyprus and Rhodes as early as 1700 B.C., and by 1250 B.C. they were venturing beyond Gibraltar.

Probably the peak of efficiency of rowed vessels was reached by the Roman triremes. Three banks of oars pulled by synchronized teams of galley slaves drove these ships through the water at speeds reputedly up to six knots. The method which the ancients used to row their ships differed somewhat from the customary method of employing oars today. Many of these large galleys were double-ended with

a rudder fore and aft. The oars were similar to those now used except that they were broader and flatter. The rowing motion was not a fore and aft oscillation but an athwartship movement with the oarsmen facing forward and outboard. The action resembled sculling rather than rowing and thrust was generated during both the inboard and outboard strokes. The oars were normally in a nearly vertical position thus requiring the triremes to be built with considerable flare to accommodate the three banks of oarsmen. When aground, the oars were used as props to support the vessel.

The rowed galley maintained its supremacy as a man-of-war well into the fourteenth century; but the advent of gunpowder sounded its death knell. Because fighting could be carried out at greater ranges, sail became the necessary source of propulsion for a vessel of war.

EARLY PADDLE WHEEL DEVELOPMENTS

It must have been noticed early in history by paddlers and oarsmen that although they obtained propulsive thrust with the aftwards motion of their blades, they lost speed during the forward motion. In spite of the fact that this forward stroke offered a restful interlude, it did not contribute to the propulsion of the vessel. One obvious solution was the sculling stroke mentioned above. The other is a continuous paddling action which could be obtained by the use of a paddle-track or paddle-wheel.

The Chinese used paddle-wheels in ancient times, and it is also said that the Roman army under Claudius Caudex was transported in vessels propelled by paddle-wheels which were driven by oxen. An ancient bas-relief said to have been cut in 527 A.D., Figure 1, shows such a vessel with three paddle-wheels on each side driven by three pairs of oxen.

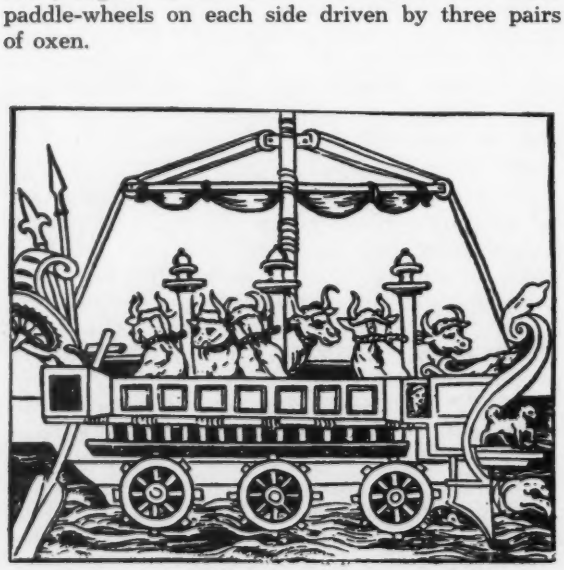


Figure 1. Early paddle-wheeler—6 oxen power

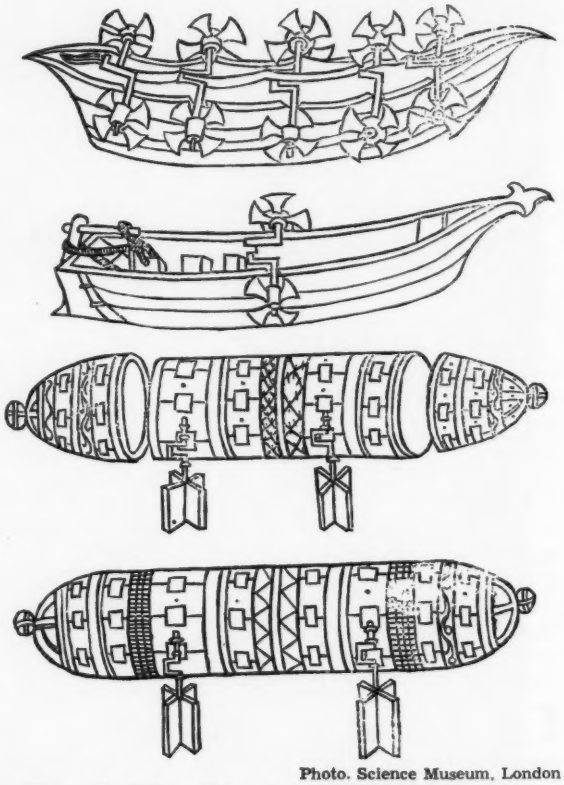


Photo. Science Museum, London

Figure 2. Galleys driven by paddle-wheels circa 1534

In the fifteenth and sixteenth centuries paddle-driven boats with the propulsive power supplied by either animals or human beings were not uncommon. Robertus Valturius in "De Re Militari Verona," of 1472, gives an account of two galleys with five paddle-wheels port and starboard connected athwartships by axles with a crank in the center for hand operation. In 1578 William Bourne wrote: *"You may make a boate to goe without oars or sayle by placing of certain wheeles on the outside of the boats, in that sort that the armes of the wheeles may goe into the water and so turning the wheeles by some provision, and so the wheeles shall make the boate goe."* And, in 1588 A. Ramelli described a ferry boat propelled by four paddle-wheels on each side, with each turned by a man on a winch. A woodcut made during this era, Figure 2, shows four different galleys fitted with paddle-wheel drives.

The ingenious device shown in Figure 3 was purported to be in operation around 1590 for hauling a laden ship upstream. A line was wrapped around a drum on the shaft connecting the two paddle-wheels of the device and then the line was run upstream and passed around a sheave fixed to a moored boat. From the sheave the line extended to a small towboat which was fitted with large flat boards to give it a high longitudinal resistance. As

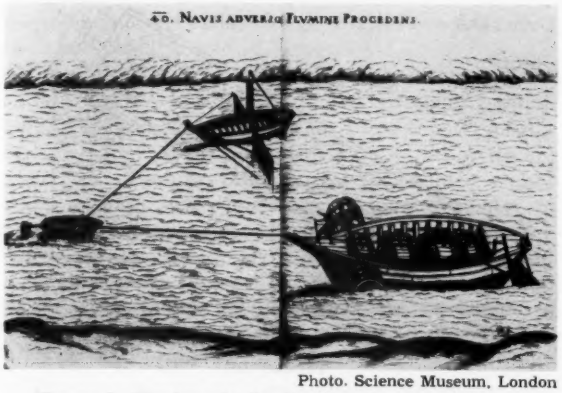


Photo. Science Museum, London

Figure 3. Towing rig for hauling barges upstream

this towboat drifted downstream, the resulting pull on the line would revolve the paddle-wheel axle thus propelling the cargo ship upstream. Presumably when the cargo ship reached the moored boat, the resistance boards on the towboat would be retracted inboard and the whole operation moved further upstream.

STEAM FOR SHIP PROPULSION

It is difficult to tell from history when it occurred to man that power other than animal or human muscle might be used to propel a vessel through the water. In 280 B.C., Hero is said to have made a toy moved by steam power. In 220 B.C., Archimedes used steam jets to repel the invaders of Syracuse. Anatheminus, an architect, first demonstrated the real power of steam in 540 A.D. by shaking a building with steam-filled risers. In the thirteenth century, Roger Bacon wrote, *"Art can construct instruments of navigation such that the largest vessels, governed by a single man, will traverse rivers and seas more rapidly than if they were filled with oarsmen."* In the sixteenth century, Leonardo da Vinci first suggested the use of steam for propelling ships.

There exists a legend that Blasco de Garray, a native of Biscay, Spain, propelled a vessel by steam in 1543 off Barcelona. The vessel, named *La Trinidad,* displaced 209 tons and was said to have a propulsion system consisting of an immense cauldron of boiling water which served to energize its two paddle-wheels. After the first trials, it was claimed that De Garray disassembled his propulsion plant and hid it away ashore never to demonstrate it again because of the fear it aroused in the hearts of the local populace.

This story was first published by Thomas Gonzales in 1825, and was accepted as fact for many years. In 1858, however, John MacGragor read a paper before the Society of Arts taking violent issue with the account. MacGragor had visited Simancas near Valladolid, Spain, and while there had read two letters signed by Blasco de Garray. These letters described the 1543 experiments and stated that the motive power was provided by some 25 men working the paddle-wheels. No factual evidence has been found showing that De Garray ever employed steam or even contemplated its use.

In the late sixteenth and early seventeenth centuries, valid records began to appear regarding the application of steam to the powering of ships. Mathesius invented a whirling eoliphile in 1563 which was a sphere made to revolve by steam. De Caus, in 1563, in "Raison de Force" described a spherical vessel acted upon by the power of steam. Both of these early engineers foresaw the potential use of this form of power for ship propulsion.

David Ramsey and Thomas Wildgoose patented a steam engine in England in 1618. This engine was to *"make boates for the carryage of burthens and passengers upon the water as swifte in calms and more saft in stormes than boates full sayled in greater wynes."* In 1630, Charles I granted to the same David Ramsey, by then a groom of the privy chamber, a patent *"to make boates, shippes, and barges to go against strong wyne and tyde."*

During 1651, an anonymous pamphlet claimed that an engine had been built at Lambeth which could drive boats or ships upriver against the stream. The Marquis of Worcester published a book in 1663 entitled, "A Century of the Names and Scantlings of Inventions" in which he described a steam pump, and also a boat which was to move against the stream by using the force of the stream. This latter invention seems to have been somewhat similar to that shown in Figure 3. However, in Worcester's boat the towline was anchored at the upstream end and wound around the paddle-wheel axle of the cargo boat in such a direction that the force of the stream would turn the paddles, reel in the line, and pull the boat upstream.

THE CONTRIBUTIONS OF FAMOUS SCIENTISTS TO SHIP PROPULSION

Up to this point in history, the manual or steam driven paddle-wheel appeared to be the most popular idea put forth for propelling ships. And yet, the fundamentals of other methods of ship propulsion were known. Scientists prominent in other fields had contributed ideas which later were to have an important effect on future propulsion developments. The three men whose ideas probably had the greatest influence on progress are seldom mentioned as inventors of ship propulsion devices. They are Archimedes, Leonardo, and Hooke.

Archimedes was the earliest scientist whose work had a lasting effect on the history of naval architecture and ship propulsion. He lived from 287 to 212 B. C. His contributions can be regarded in both a positive and negative sense. His discovery of the principle of flotation and his many machines exploiting mechanical advantage represent contribu-

tions of inestimable value to the naval architect and marine engineer. Archimedes, however, devoted much of his energy and talent in later years to devising machinery for the destruction of shipping. His accomplishments in this area may be of interest to the ordnance engineer but hardly to the shipbuilder. His screw pump, although a marvelous device for irrigating the fields of Syracuse, was to cloud the thinking of ship propulsion inventors for many years.

Concerning the principle of flotation, the story of its discovery is worthy of retelling. As reported by Vitruvius, King Hiero of Syracuse awarded a contract to make a gold crown which was to be set up in a shrine. He weighed out the exact amount of gold for the contractor who duly finished the crown and submitted it to Hiero for approval. The weight of the crown was exactly equal to the original weight of gold issued, yet there were rumors that the contractor had removed a certain portion of the gold and replaced it with an equal weight of silver. Hiero called in his chief scientist, Archimedes, to uncover the fraud, if any.

The solution of the problem came to Archimedes in his bath from whence he made his famous ungarbed dash to his laboratory where he measured out two masses, one of gold and one of silver, equal in weight to the crown. He immersed each of these in a full container of water and then measured the overflow. Next he made a similar measurement using the crown. He found that the volume of water displaced by the crown was greater than that displaced by the gold and less than that displaced by the silver. He then calculated the proportions of silver and gold in the crown thus exposing the contractor's fraud. Carrying his newly discovered principle further, Archimedes applied the same logic to floating bodies and evolved the principle of flotation.

Geometry was Archimedes' main obsession in life; he constructed many machines of various types to demonstrate geometrical principles. Most of these devices involved some means of multiplying force such as the lever, the screw jack, and the triple pulley. When invasion of Syracuse by the Roman Marcellus was threatened, King Hiero urged Archimedes to convert these devices to weapons of siege warfare. So successful was he that almost singlehandedly he delayed the fall of the city by more than two years.

His devices were said to have hurled all sorts of missiles and huge masses of stone against both the land forces and the ships at sea. Beams projecting out from the walls of the city dropped large weights on the ships while other vessels were picked up by tremendous iron claws, raised from the water, and dashed down on their sterns. As a destroyer of the products of the shipbuilding industry Archimedes seems to be without peer in history.

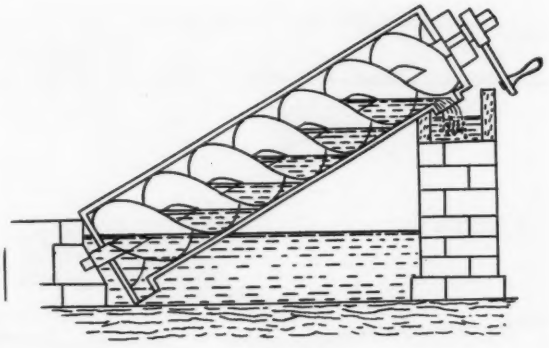


Figure 4a.

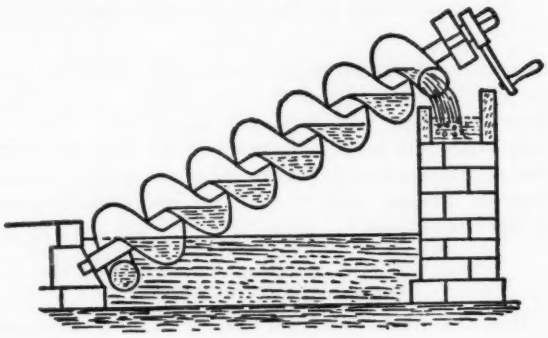


Figure 4b.

Figure 4. Two Types of Archimedian Screw Pumps

One of Archimedes less destructive inventions was the screw pump which has had a profound effect on marine propulsion. This pump was used to supply the irrigation ditches of Syracuse, and has been used for this purpose in countries throughout the world. As shown in Figure 4a, this pump consists of an impeller built of a plate wrapped helically around the drive shaft and housed in a casing which fits closely the outer rim of the helix. An alternative design of this pump employing a helically wrapped tube is shown in Figure 4b.

The housing of the Archimedian screw pump forms an integral part of the device and is essential to its lifting power as can be seen from the diagrams. Yet, later propeller designers were to forget the essential part played by the housing and the "Archimedian Screw" was misapplied to the propulsion of ships for a number of years before more logical minds prevailed. Thus, Archimedes inadvertently had a deleterious effect on the development of marine propulsion systems without even considering this field of scientific pursuit.

Voltaire said, *"There is an astonishing imagination, even in the science of mathematics.—We repeat, there was far more imagination in the head of Archimedes than in that of Homer."* Had this mighty intellect been applied to the movement of ships through the water rather than to their destruction,

the science of propeller design might have advanced far more rapidly.

Leonardo da Vinci, on the other hand, was fascinated by ships and by schemes for propelling them. Unlike Archimedes, his love for ships was forcefully demonstrated when he refused to build a diving apparatus which he invented for fear that it would make it possible for men operating underwater to damage shipping. Leonardo's early life in Florence seems to have been devoted primarily to art and music, but when he moved to Milan in 1482 he added the responsibilities of ducal engineer to Lodovico il Moro to his already crowded schedule. In this capacity he acted as architect of various public buildings, planned and constructed the Martesana Canal, and participated in numerous military expeditions.

In 1502 da Vinci became military engineer to Cesare Borgia, a position which he maintained for some considerable time. It is during this period that he evolved many of the inventions with which he is credited. Although his writings on engineering subjects are meager, his detailed sketchbooks leave no doubt as to his engineering ability.

Leonardo's active interests included art, music, mathematics, optics, mechanics, architecture, ordnance, botany, anatomy, geology, geography, hydraulics, naval architecture, aerology, and cosmology. It was at first his artistic inclinations which led him to study the basic sciences of his day in order to interpret more accurately the things which he saw into a form in which others could visualize them. Thus, his studies of anatomy gave him the capacity to create paintings of the human form more realistic than those of his predecessors; and his studies of mathematics gave him a greater insight into geometrical presentations and perspective.

His interest in these fundamental sciences paved the way to an examination of other fields of scientific endeavor. The page from his sketchbook reproduced in Figure 5 is an example of the minute detail involved in his thinking. Here is a turbine driven, paddle-wheel boat with an intricate gearing system to reduce the high speed of the turbine to the low speed required for the paddles. It was not until the second half of the nineteenth century that such gear trains were actually employed in marine propulsion systems and yet here in the early sixteenth century their feasibility was clearly shown.

Leonardo also considered the use of the Archimedian screw in some of his inventions. To the screw pump he added a mechanical gear train which greatly improved its performance. His helicopter utilized a conically tapering Archimedian screw as its lifting device. But the screw propeller, as we know it today, was not foreign to his thinking. He invented the automatic turnspit, or smoke-jack which employed a screw propeller driven by hot air as its motive device.

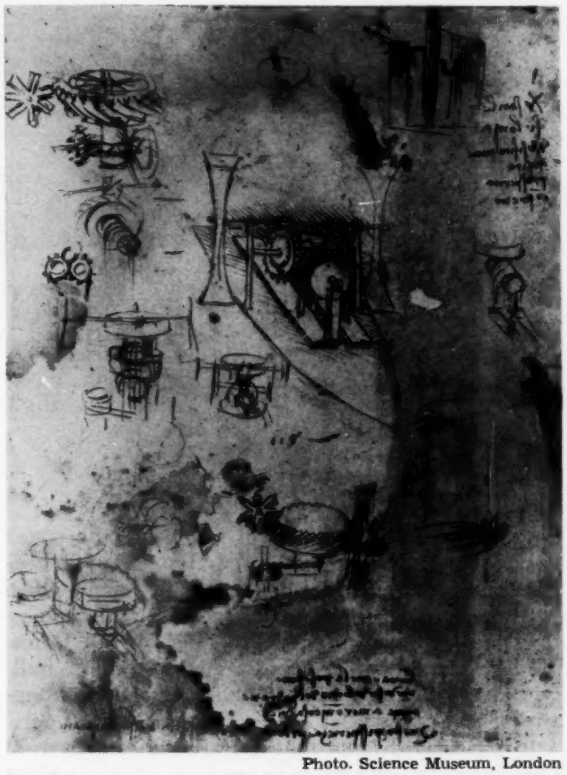


Photo. Science Museum, London

Figure 5. A page from the sketchbook of Leonardo da Vinci

The smoke-jack is an interesting mechanism which was apparently used from the time of Leonardo up through the eighteenth century. It consisted of a propeller connected by mechanical gearing to a spit, or in modern terminology, a rotissary. The propeller was fitted in the stack or chimney above a fireplace and was rotated by the rising hot air; this propeller in turn rotated the roast on the spit. The hotter the fire, the higher was the speed of rotation. This device is often refered to by later "inventors" of the screw propeller.

Other mechanical inventions of da Vinci, related to the fields of naval architecture and marine engineering, were a derrick, the circular pulley, the screw jack, a wire tensile-strength testing device, a variable speed drive, and a device for converting reciprocating motion into rotary motion.

Leonardo was an avid student of the motion of water. He made a detailed analysis of the flow in a whirlpool and of the flow of water through locks and dams. He applied the results of his hydraulic studies in the design of a two-level canal lock, a water lift, a hydraulic screw, a water wheel, a bilge pump, and other devices for the movement and control of fluids.

Before Leonardo's time ship hulls were fitted with round bottoms throughout their length. After a

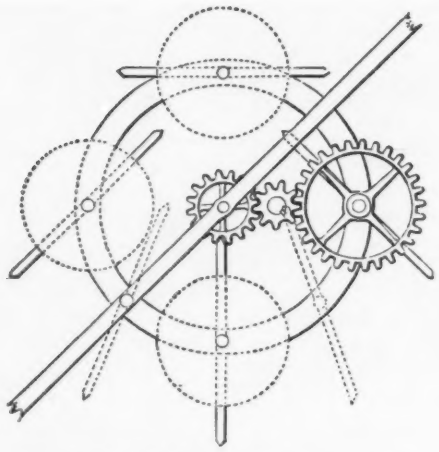


Figure 6. Hooke's horizontal watermill

lengthy study of the forms of fishes and the water flow around them he proposed the use of a vee-bottom to improve directional stability and reduce resistance. This is the earliest example of the employment of double curvature in ship hull forms. He also proposed the use of a double hull, or hull-within-a-hull, for increasing the watertight integrity of naval vessels.

It is clearly evident that the diversified talents of this sixteenth century engineer had a lasting effect on the design of ships' hulls, machinery, and propulsion devices.

One of the greatest scientific minds of the seventeenth century was Robert Hooke. Like Archimedes and da Vinci, his genius lay not only in the broad understanding of many branches of science but in the insight which he had in every aspect of mechanics and physics in which he indulged. Hooke was a pioneer in microscopic biology, scientific meteorology, geology, and in the kinetic theory of matter. He invented the balance wheel for watches, the first practical compound microscope, the refractometer for liquids, the first wheel-barometer, a sealed alcohol thermometer, an indicating hygrometer, a wind gage and self measuring rain gage, a multi-channel weather data recorder, the iris diaphragm, and a helioscope. He was an accomplished draftsman and, as an architect, designed several well known London buildings. He was the supreme instrument maker of his time.

Robert Hooke is best known for Hooke's Law (mechanical strain is proportional to stress), but he too indulged in the advancement of the science of marine propulsion. In his "Philosophical Collections" printed by the Royal Society in 1681, Hooke proposed what he called a horizontal water-mill. This device, shown in Figure 6, is what would now be termed a vertical axis propeller. A series of wooden vanes were pinned perpendicular to a circular rotor and geared to a central shaft. The gearing was so devised that for each complete revolution of the rotor the vanes would rotate 180° on their own axes. When placed in the proper angular position relative to the mill race, the vanes on one side would be perpendicular to the stream whereas those on the other side would be edge-on to the stream. In this manner the device would be forced to revolve and drive a mill.

During the course of his work in meteorology Hooke developed a windmill-type air velocity meter. In 1683 he adapted this device for the measurement of water currents with great success. The device is shown in Figure 7. Hooke also suggested using this as a propeller for driving ships through the water.

OTHER PROPULSION METHODS

Hydraulic jet propulsion first came into the limelight somewhat prior to Hooke's marine inventions. In 1661 Toogood and Hayes described a ship which had a channel through the center in which was installed either a plunger or centrifugal pump. Water was sucked in at the bow-opening of the channel, accelerated by the pump, and ejected at the stern, thus propelling the ship. This seems to be one of the earliest references to a form of propulsion which has been proposed often in the intervening years.

One inventor who maintained an active interest in marine propulsion over a number of years was a Monsieur Du Quet. His inventions involved using the forces of nature as a source of power rather than animal muscle or steam. In 1699 he devised a machine for drawing vessels upstream against a

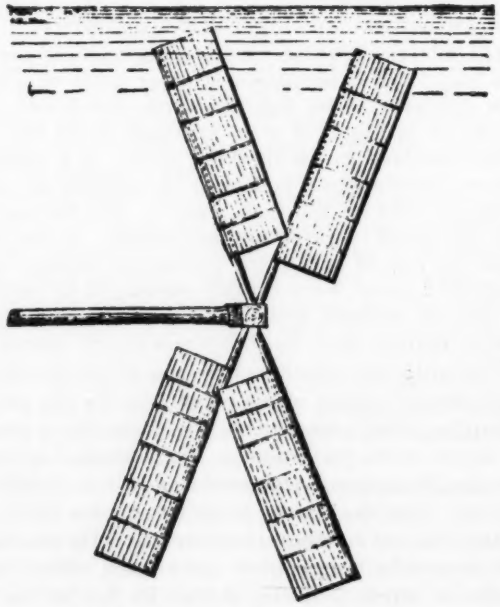


Figure 7. Hooke's screw propeller

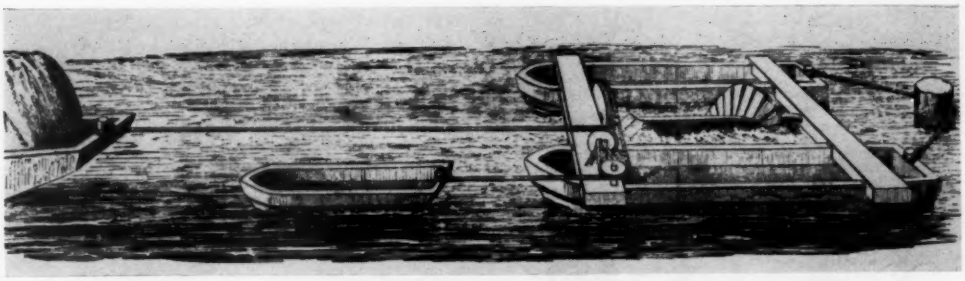


Figure 8. Du Quet's towing rig

current, Figure 8. This towing machine utilized a partially submerged Archimedian screw made up of a group of radial boards helically displaced around an axle. The screw axle was mounted between a pair of boards which straddled twin hulls. This towing contrivance was then anchored or moored in the stream. From the bow of the vessel to be hauled upstream a line ran to the towing machine, passed around a pulley arrangement mounted on the screw axle, and thence passed to a drag boat which maintained a tension on the system. As the screw revolved in the flowing stream the barge would be pulled toward it. Du Quet called his screw "revolving oars". Experiments with this device were conducted in both Le Havre and Marseilles, but it apparently was too inefficient to be successful.

M. Du Quet came up with another marine propulsion invention in 1712. This system, shown in Figure 9, used the wind as a source of propulsive power. The windmill, which could be rotated to obtain optimum use of the wind velocity, drove a paddle-wheel through a rope and pulley system, which in turn propelled the vessel. Again, there is some question as to the success which was achieved by this scheme.

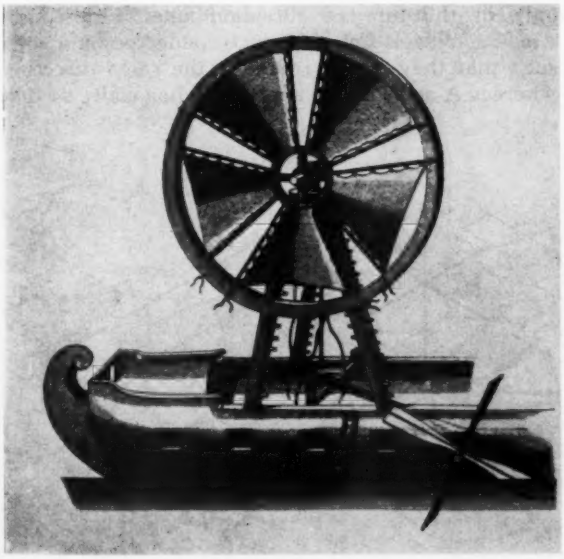


Figure 9. Du Quet's wind driven paddle-wheeler

PRACTICAL APPLICATIONS OF STEAM TO SHIP PROPULSION

Meanwhile, the application of steam to ship propulsion was receiving more studious attention. In 1688, Denis Papin of Blois, France, while serving as professor of mathematics at the University of Marburg, proposed the use of gunpowder to drive the piston of an engine. In 1690 he published a description of a steam cylinder and a safety valve and suggested their employment to power ships. Later, in 1695, Papin demonstrated how the condensation of steam could be used to create a vacuum in a cylinder for the purpose of displacing a piston.

Papin finally built a steamboat, which is described in his correspondence with Liebnitz, using his engine to drive paddle-wheels. In 1707 he demonstrated his boat on the Fulda River. The boat was destroyed by rivermen who were afraid of this fire-belching craft. Discouraged, Papin retired to London where he died three years later. This remarkable French engineer was the first to demonstrate experimentally the feasibility and practicality of using steam to propel ships.

A contemporary of Papin was Thomas Savary, an Englishman, who first experimented in ship propulsion with a paddle-wheel boat manually operated through a capstan. Apparently independent of Papin, Savary also discovered in 1698 the means of moving a piston by a vacuum created by steam condensation. Savary patented his "fire engine" but never actually installed it as a ship powering system.

The first steam boat which was both patented and described in detail was the work of Dr. John Allen of England. This patent was obtained in 1729. Interestingly enough Dr. Allen rejected the idea of using a paddle-wheel and suggested a form of jet propulsion. Motive power was to come either from the crew operating an air pump or from two Newcomen steam engines pumping jets of steam or air from the stern of the vessel at five second intervals. Dr. Allen also suggested the possibility of exploding

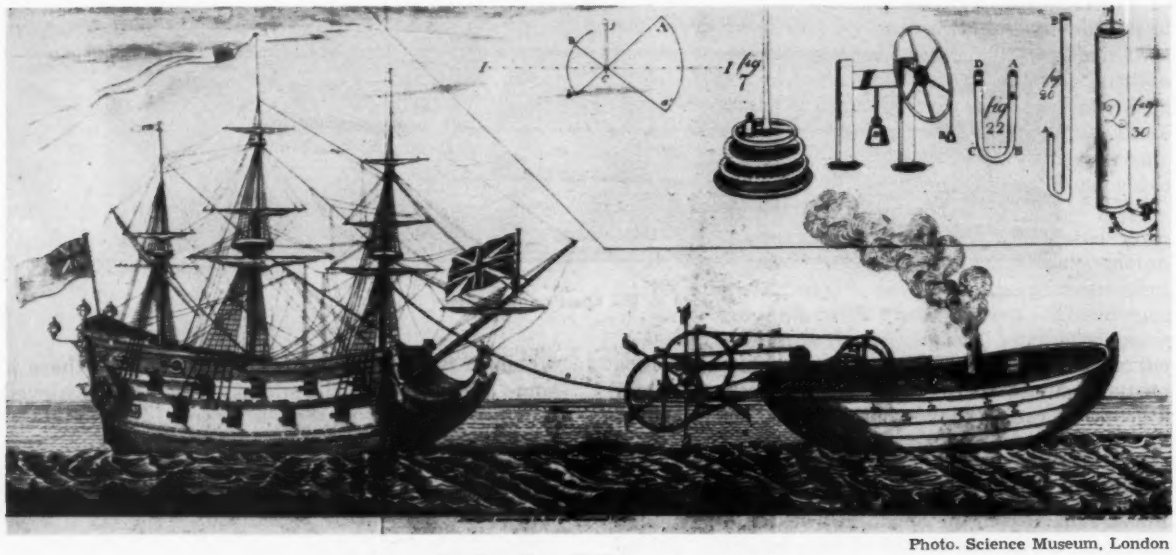


Photo. Science Museum, London

Figure 10. Jonathan Hulls' proposed towboat

gunpowder in a chamber so devised that the explosive force would drive water aft and thus propel the vessel.

To Jonathan Hulls of Hanging-Aston, Gloucestershire, England, often goes the credit for inventing the steamboat, although later revelations indicate that credit is due Denis Papin. Hulls, a horologist by trade, obtained a patent in 1736 for a *"machine for carrying ships and vessels out of or into any harbor or river against wind and tide."* Although the nature of his invention was not disclosed in his patent, Hulls published a pamphlet in 1737 which described its workings. In this pamphlet he also philosophized a bit on the problems of inventors:

> "There is one great hardship lies too commonly upon those who propose to advance some new though useful scheme for the public benefit. The world abounding more in rash censure than in a candid and unprejudiced estimation of things, if a person does not answer their expectations in every point, instead of friendly treatment for his good intentions, he too often meets with ridicule and contempt. But I hope this will not be my case, but that they will form a judgment of my present undertaking only from trial. If it should be said that I have filled this tract with things that are foreign to the matter proposed, I answer: there is nothing in it but what is necessary to be understood by those who desire to know the nature of that machine which I now offer to the world, and I hope that, through the blessing of God, it may prove serviceable to my country."

Hulls made an extensive investigation of the potential utilization of his device, a study which now would be called operations research, and came to the conclusion that the ideal vehicle would be a towboat which could be used to haul barges or other craft. He proposed a stern-wheeler driven by a steam engine, the advantage of the stern-wheel being that with the wind coming from the bow the exposed section of the paddles would not be adversely affected due to the shielding of the hull; with the wind abeam the exposed paddles would present no surface to be affected; with the wind astern the effect would be favorable. His proposed towboat is shown in Figure 10.

In the early steamboats with atmospheric engines the conversion of reciprocating motion to rotary motion posed a distinct problem and the simple crank did not always appear to be the solution. Jonathan Hulls solved this problem for his design in a rather novel fashion as shown in Figure 11. Wheels A, B, and C were affixed to one axle. The other axle passed through wheels D and F which were mounted with ratchets and pawls so that the axle could turn only in the forward direction relative to these wheels. Wheels C and F were connected by a rope such that they would rotate in the same direction whereas A and D were connected diagonally so that

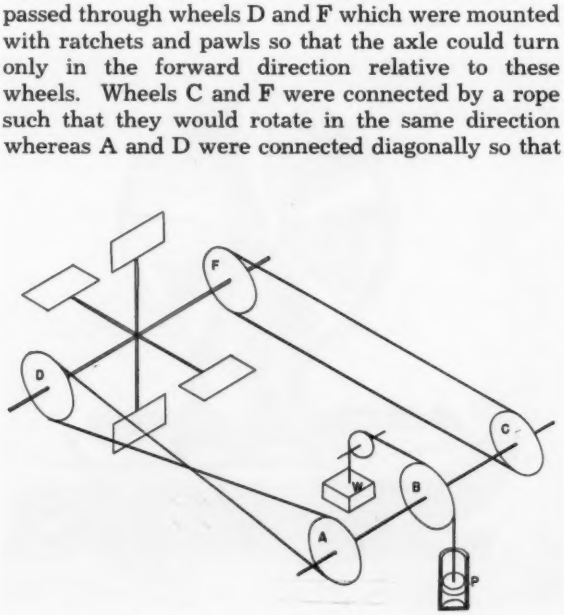


Figure 11. Jonathan Hulls' Crank Mechanism

they would rotate in opposite directions. Another rope connected the reciprocating piston P to the wheel B and extended over a pulley to the hanging weight W. As the piston moved downward on its power stroke, wheels A, B, C, and F would rotate clockwise driving the paddle-wheel in the ahead direction and raising the weight W. Wheel D would rotate counter-clockwise. At the completion of the power stroke the weight W would descend turning all wheels in the opposite direction. This motion, through the ratchet on wheel D, would continue to drive the paddle-wheel in the ahead direction. The reversed rotation of the wheel B would also raise the piston and the cycle was then repeated.

Hulls, despite his detailed analysis and obvious ingenuity, was looked upon as a crackpot. A common ditty in his home town was:

Jonathan Hulls
With his patent skulls
Invented a machine
To go against wind and stream
But he, being an ass,
Couldn't bring it to pass
And so was ashamed to be seen.

Thus was Hulls met with *"rash censure . . . . . ridicule and contempt"* rather than *"friendly treatment for his good intentions."* He received no support for his invention and died in poverty.

THE SCREW AND DUCK-FOOT PROPELLERS

While Papin, Savary, Allen, and Hulls were demonstrating how steam could be applied to propel boats, improvements were being made in the screw-pump. Leupold, in his "Theatrum Machinarum" published in 1742, described several arrangements of Archimedian screws driven by windmills for raising water from lowlands. Two of these types shown in Figure 12, exhibit simplified forms of construction of the screw. In the first, the blade elements consist of a flat plate, wedge-shaped section attached to a cylindrical disc. The second type of element is similar, but with two wedges 180° apart. By stacking these elements on a shaft and overlapping them slightly, Archimedian screws of single and double threads respectively were formed.

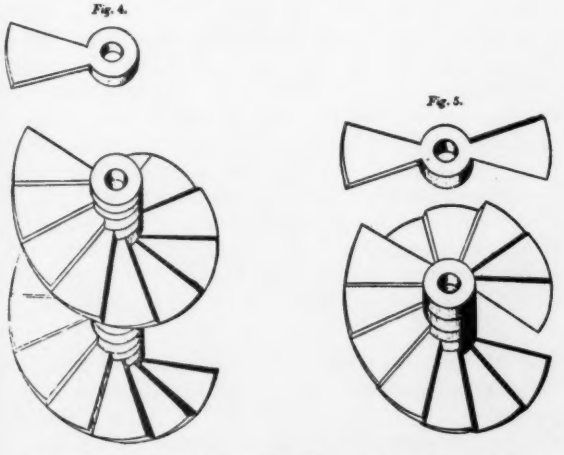


Figure 12. Leupold's simplified Archimedian screws

Figure 13. Emerson's variable pitch screw pump

In his "Principles of Mechanics", published in 1754, W. Emerson described the Archimedian screw pump shown in Figure 13. This design was unusual primarily because a variable pitch was employed in the screw thread. Emerson stated, *". . . . . that for every ten inches in circumference of the axis you must rise seven inches in length. But at the top it would be better to rise faster so as to have its surface almost perendicular to the stream."*

As the paddle-wheel improved, and as the Archimedian screw underwent developmental changes, other forms of propellers were being proposed. M. Bouguer published his "Traite du Navire" in Paris in 1746. There he first described a form of duck-foot propulsion and also restated Hooke's proposal of the underwater windmill. Bouguer described one propulsion arrangement which consisted of two paddle-plates placed at the stern of the vessel. These paddle-plates, which oscillated fore and aft, opened like a double door on the backstroke and folded together on the forward stroke. Although he felt it lacked sufficient propulsive thrust he also described a device with revolving arms like the vanes of a windmill. This latter device also was to be placed at the stern, but the method of driving it was not specified.

In 1753, the French Academy of Sciences held a contest for the description of the most advantageous manner of supplanting the action of wind on large ships. Entrants in the contest were such famous

men as Mathon de la Cour, Leonard Euler, the Swiss mathematician, and Daniel Bernoulli, the Swiss philosopher. Euler had won a similar contest for the best treatise on the masting of vessels in 1726, and Bernoulli had shared a double prize with his father, Jakob, in 1734 for an essay on the causes of the different inclinations of the planetary orbits.

Both Euler and de la Cour suggested the use of paddle-wheels. Bernoulli, however, expounded on the earlier theories of Bouguer. He suggested inclined planes acting obliquely on the water which moved circularly like the vanes of a windmill resembling the sculling mode of propulsion practiced by the ancients. Bernoulli proposed installing one of these propellers on each side of the vessel and two more at the stern. The wheels were to be about six feet in diameter and were to be completely immersed in the water. They were to be rotated either by steam engines or by horses. For this exposition Bernoulli was awarded first prize.

In 1759, M. Genevois, a Swiss cleric, wrote at great length on what he called the *Great Principle*. His lengthy expositions left some doubt as to exactly what constituted his *Great Principle*, but the general idea seemed to be that he would store energy in large springs which would then be used to drive oars and thus propel a vessel. Although admitting to the possibility of using a steam engine to deflect his springs initially, M. Genevois was much more intrigued with the idea of using the explosive force of gunpowder as the primary source of energy. His oars resembled to some degree the feet of aquatic birds opening when moving aft and closing when moving forward.

In his "Theory of the Archimedian Screw", M. Paucton, in 1768, suggested the use of a *Pterophore*, composed of the circumvolution of the thread of a screw around a cylinder, as a propeller. Paucton felt that these screws should be mounted either as twin units port and starboard or as a single unit at the bow. As did others of his time, he believed that this screw would be equally efficient either totally immersed or with only one half of the screw in the water.

In France, the Marquis de Jouffroy was working tirelessly on the development of a workable steamboat. In 1776 he constructed a vessel which was said to swim like a duck. He found that this principle lacked efficiency and abandoned it in favor of the paddle-wheel. His patent application of 1783 showed a *Plan et profil du Bateau a Vapeur* which is reproduced in Figure 14. A model of this 140 foot steamboat is shown in Figure 15. The boiler and single cylinder steam engine driving the two side paddle-wheels can be seen. Unfortunately the French Revolution forced the Marquis to flee the country before a patent could be granted.

The idea of using buoyant floats crops up from time to time particularly in old French records. These consisted of either floats mounted on a wheel or a chain of floats driven along the side of a ship's hull. One such invention was the work of the Abbe Darical in 1782. In that same year, M. Desblancs constructed a model of a steamboat propelled by a chain of floats supported by wheels at the forward and after ends of a vessel. These types simulated the paddle-track or the paddle-wheel but with buoyant chambers substituted for the paddles. This idea seems to be the predecessor of the buoyant wheel, and probably is the origin of the use of the word *float* to describe paddle blades. Most attempts along these lines appear to have been quite unsuccessful.

In Britain, the Earl of Stanhope was an indefatigable proponent of various forms of duck-foot propulsion. His first attempt was the construction of a *Vibrator* type of propulsion device. This device consisted of a vertical flat board pinned to the vessel

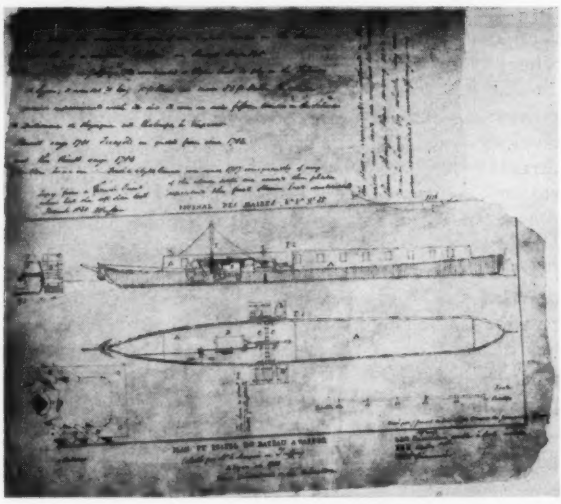


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Figure 14. Patent application of the Marquis de Jouffroy

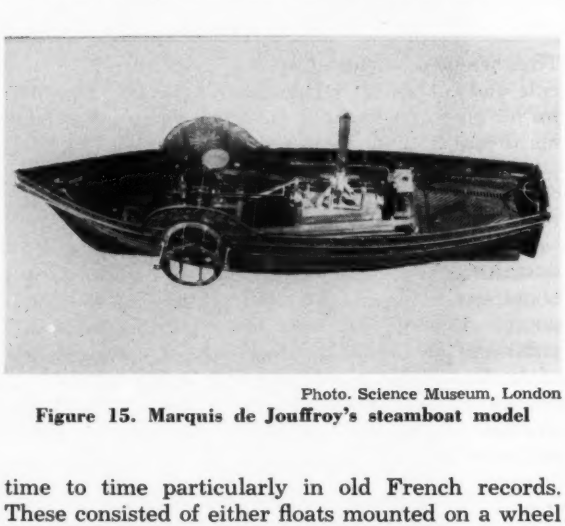

Photo. Science Museum, London

Figure 15. Marquis de Jouffroy's steamboat model

at the gunwale. The upper end of the board was oscillated back and forth by means of a reciprocating steam engine. To the lower, or submerged portion of the board, two additional boards were hinged on the after side. The hinge arrangement was such that as the blade moved forward, the hinged boards lay flat and parallel to the centerline of the vessel. As the blade moved aftwards, the hinged boards would open up against stops and provide a forward thrust.

In 1795, Stanhope built a boat with two large umbrella-like cones on either side. These umbrellas opened and closed as they were moved fore and aft. His greatest speed attained with this boat was on the order of three miles an hour. Another inventor of this era built a vessel with a series of collapsible cones on both sides of the vessel. His cones were attached at their apexes to a cable on each side of the ship. The cable was oscillated back and forth to provide a propulsive thrust.

Across the Atlantic a Connecticut carpenter, Elijah Ormsbee, was also intrigued with the idea of a steam propelled duck-footed vessel. He built such a boat and made several trips in it from Pawtucket to Providence and back. His *goose-foot* paddles seem to have been similar to the *Vibrator* of Lord Stanhope. Lacking means for further exploitation of his ideas, Ormsbee was forced to return his borrowed boat and the copper still which he used for a boiler to their respective owners.

Although its fundamental inefficiency has been proven time after time, the idea of propelling a ship with some form of fore-and-aft oscillating plate is often reproposed. Yet, even those inventors who worked on such impractical forms of propulsive mechanisms could see the effect that mechanical drives were to have in the future. Speaking of the application of steam machinery to ships, Lord Stanhope said, "*. . . . . it will shortly render all existing navies of the world (I mean military navies) no better than lumber. For what can ships do that are wholly dependent upon the wind and weather against fleets wholly independent of either?*"

SUBMARINES

All of the craft mentioned up to this point have been intended to be surface vessels. Although several of them maintained that enviable status for only a short time, they were not conceived by their inventors to be submersible. Yet, the submarine has had a profound effect on the development of ship propulsion mechanisms. This is due to the fact that its propelling system must be designed for continuous immersion and is therefore subject to more exacting requirements than similar systems on surface vessels.

There are early records in ancient Greek and Arabian history which indicate that diving bells were constructed and used in the sieges of Tyre and Ptolemais. But, it was not until 1580 that any record appeared describing a self-propelled craft designed for submerged operations. In that year, William Bourne, a British naval officer, designed a completely enclosed boat which could be submerged and rowed under the surface. Its hull was a wooden framework covered with leather. For submerging, the sides were contracted by the use of hand vises. Bourne never built his boat, but one of similar construction was sponsored by Magnus Pegelius and was launched in 1605. By some oversight its designers did not consider the tenacity of underwater mud. The craft was buried in this viscous substance during her first underwater trials.

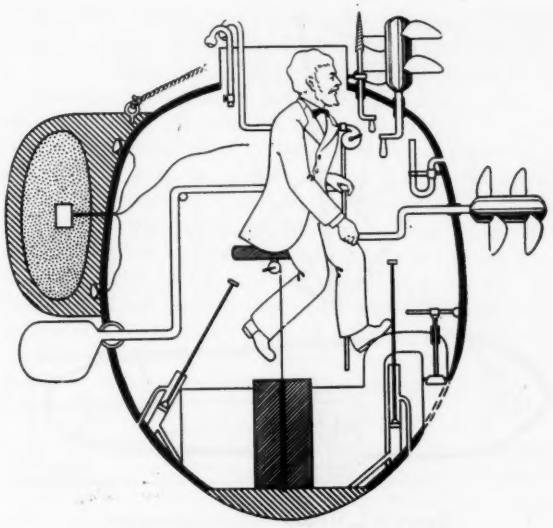

Figure 16. David Bushnell's *Turtle*

The credit for building the first workable submarine goes to Cornelius Van Drebel, a Dutch physician. In 1624, he constructed a craft similar in concept to those of Bourne and Pegelius. The hull was of leather and the craft was propelled, both surfaced and submerged, by oars. Repeated tests were made on this and two larger boats in the Thames River at depths of twelve to fifteen feet. James I of England was said to have ridden in one of these craft to demonstrate its safety. Yet, the idea did not seem to be utilized further at that time.

In 1652, Le Son, a Frenchman, built the *Rotterdam,* a wooden submarine 72 feet in length and with a beam of 8 feet. The sides tapered in sharply at the bow and stern, and a large amount of flare was used. Iron tipped legs were provided for bottoming the submersible, and midship paddle-wheels were installed for propulsion. About the same time J. Day, an English mechanic, built a boat which submerged to a depth of 30 feet and remained there for 24 hours. In an attempt to repeat the experi-

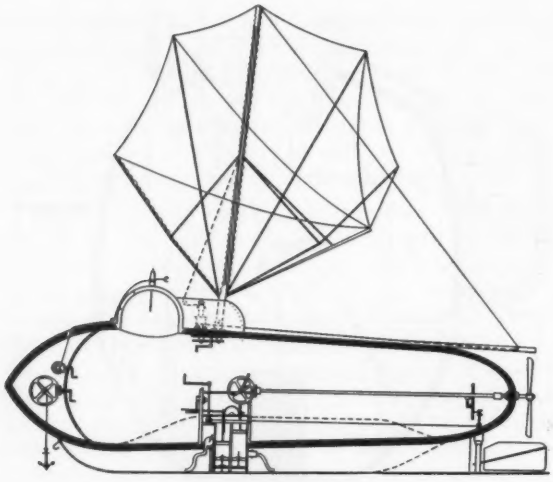

Figure 17. Robert Fulton's *Nautilus*

ment with a converted 50 ton sloop, the vessel failed to return to the surface and Day was drowned.

There are few records which indicate any actual application of the screw propeller or underwater windmill during the early eighteenth century. Yet, David Bushnell in his submarine, *Turtle,* came up with a fairly advanced model according to the drawing shown in Figure 16. This submersible was developed during the Revolutionary War. It had a hand-operated screw propeller for forward motion and another screw propeller on a vertical axis for depth control. The vessel was first used in an attempt to blow up the British man-of-war, *HMS Eagle.* The idea was to come up under the *Eagle,* drill a hole in her hull, and attach a charge with a time fuse. After repeated failures to penetrate the copper sheathing on the bottom of the *Eagle,* the *Turtle* withdrew leaving the charge behind where it exploded harmlessly.

During the struggle between England and France in the late eighteenth century, increasing interference with American shipping resulted from the high-handed tactics of Great Britain. Robert Fulton believed that a means of reducing this interference might be to supply France with an advanced weapon with which to harass the British navy. In 1797 he tried to interest the French government in the construction of a submarine, but it was not until 1800 that Napoleon Bonaparte, then first consul, advanced him 10,000 francs for the project.

Fulton's *Nautilus* was 21 feet 6 inches in length, and 6 feet 3 inches in diameter. As shown in Figure 17, the boat was shaped like a fish. It had a heavy keel for stability and two water ballast tanks for submerging. Horizontal rudders were installed for depth control; propulsion was provided by a manually operated screw propeller when submerged, and

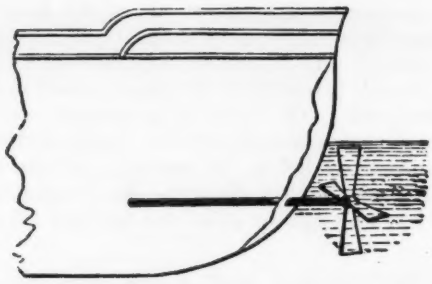

Figure 18. Joseph Bramah's screw propeller

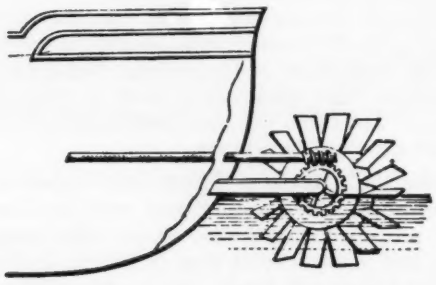

Figure 19. Bramah's stern paddle-wheel

by sail when surfaced. Fulton was unsuccessful in demonstrating the effectiveness of the craft in destroying British shipping and therefore was turned down by the French. Later attempts to sell the idea to England and the United States also failed.

Thus, the transition from oars, to paddles, to the screw propeller took place with relative rapidity in submarine propulsion developments. By 1800 it was evident that the screw was the most desirable propulsive device for this form of craft, a lesson that was not to be learned on surface ships for more than another half century.

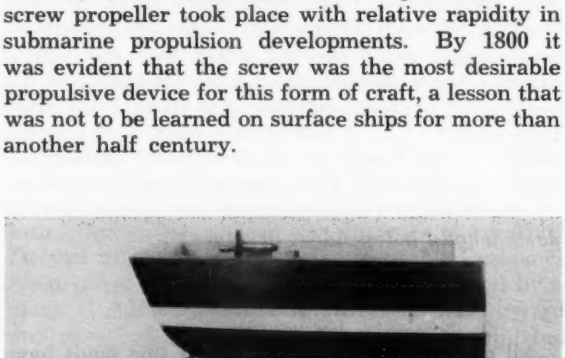

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Figure 20. Lyttleton's screw propeller

REFINEMENT OF THE SCREW PROPELLER

Other than in submarines there was relatively little application of the screw propeller prior to 1800. One instance of an air screw being used for ship propulsion was reported in the correspondence of Thomas Jefferson. Writing from Paris in 1785 describing a propulsion system he had seen in operation there, he said, *"It is a screw with a very broad or thin worm, or rather it is a thin plate, with its edge applied spirally around the axis. This being turned operates on the air as a screw does, and may be literally said to screw the vessel along. The screw, I think, would be more effectual if placed below the surface of the water."*

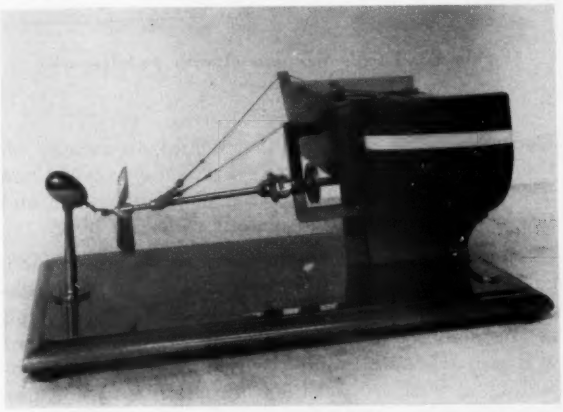

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Figure 21. Shorter's screw propeller

Also in 1785, Joseph Bramah, of Piccadilly, patented a design of a vessel with a screw propeller of the type proposed by Hooke mounted on a shaft projecting through the stern as shown in Figure 18. He planned to use a direct-drive steam engine to turn the propeller. He apparently understood the problems involved in the design of a stuffing box to seal the shaft opening and included a design of such a gland. Bramah also patented the novel stern paddle-wheel shown in Figure 19. However, his engines proved to be failures and his ships were never constructed.

A merchant, William Lyttleton of Goodman's Fields, Middlesex, applied for a patent in 1795 for an Aquatic Propeller. As shown in Figure 20, this was an Archimedian screw of three threads which were attached to the axle only at the ends. He suggested that this propeller could be mounted at the bow, at the stern, or on the sides of the ship. It was driven by an endless rope working in a sheave. In the actual installation, a ship speed of about two miles per hour was attained. It was said that Lyttleton may have brought the idea from China where he had gone on several of his trading trips.

A novel application of a very modern looking screw propeller was made in 1800 by Edward Shorter of St. Giles-in-the-fields, Middlesex. Shorter, a mechanic, applied for a patent on the device shown in Figure 21. As can be seen, the propeller shaft was mounted external to the hull and was fitted with a universal joint to permit raising the screw out of the water when the ship was under sail. To keep the screw from sinking under its own weight, a buoyant float was towed aft and stay braces were fitted to a shaft bearing which made it possible to swing the propeller from side to side for steering. The propeller shaft was to be rotated by a rope and pulley system connected to a manually operated capstan. Shorter also suggested applying a steam engine to drive the device.

Thus, at the close of the eighteenth century, screw propellers, both of the Archimedian and conventional types, were receiving some attention. However, other developments both in England and the United States were receiving much greater publicity, and therefore overshadowed the improvements made in this form of propulsion.

DEVELOPMENTS IN THE LATE EIGHTEENTH CENTURY

The most important of these developments were the inventions of a Scottish mechanic leading to the construction of a really practical steam prime mover. In 1769 James Watt of Glasgow and later of Birmingham obtained his first patent on steam engines which included the condenser, the enclosed cylinder, and the use of oil and tallow for lubrication. His second patent was issued in 1782 and covered the expansion engine, the double-acting engine, and the use of a double cylinder. In 1784 his third patent included such refinements as a parallel motion locomotive engine, and hand gear and valves. These inventions taken together covered most of the primary components of the modern steam reciprocating engine.

Watt appeared satisfied to let others worry about the installation of his engines aboard ship. Other inventors of this era, however, concerned themselves with ship installation and operation as well as engine development. The lack of communications and

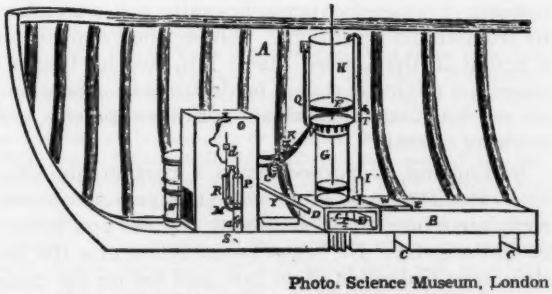

Photo. Science Museum, London
Figure 22. Rumsey's jet propulsion scheme

the lack of a good patent system during this period gave rise to many conflicting claims of discovery and many hard feelings between inventors in both England and the United States. To assign singular credit to any one inventor for the steamboat in this time of rapid development on both sides of the Atlantic is a virtual impossibility. Despite the vitriolic claims and counter-claims which flew back and forth, it is fairly obvious that the types of mechanically propelled craft which were developed were the products of the brains and tireless energy of many men striving toward a common goal. Perhaps, to gain a true perspective of the progress of propulsion developments during this period, each contributor's story can be told and then the technical and emotional interplay can be briefly explained.

James Rumsey was born in Bohemia Monor, Maryland in 1743, and later moved to Shepardstown, West Virginia where he received only a rudimentary education. He first developed an interest in steam for ship propulsion at the age of forty. By 1784 he had built an 80 foot steam propelled boat of the hydraulic jet propulsion type. He made numerous private experiments with it in the Potomac River during the ensuing three years.

On December 3, 1787 Rumsey held a public demonstration before several hundred people including General George Washington. The boat, carrying three tons of cargo, was piloted back and forth on the Potomac for two hours at a speed of three miles per hour.

A diagram of Rumsey's propulsion plant taken from his patent application is shown in Figure 22. The boiler consisted of a rectangular tank of five gallon capacity with a firebox in the bottom. Steam was fed to the bottom of the engine cylinder which acted on the atmospheric principle. Connected to an extension of the piston rod was the piston of a plunger pump. The pump suction side was open to the surrounding water through grill intakes in the fore-foot of the vessel. The pump discharged through a tunnel running along the keel and thence to a discharge opening at the stern.

General Washington was so intrigued with Rumsey's demonstration that he encouraged him to go to Philadelphia. There the Rumseian Society was formed, of which Benjamin Franklin was a member, to promote his inventions. Rumsey had applied for a patent in the United States but, fearing that his invention might be stolen, he destroyed his boat and set sail for England to obtain additional patents and working capital.

In England he turned down a partnership offer with Boulton and Watt who enjoyed an almost complete monopoly in supplying engines and boilers in that country. He began construction of a 100 ton steamboat *Columbia Maid* but, just before the river trials were conducted, Rumsey died of apoplexy in December 1792. The boat, which also operated on the hydraulic jet principle, had some success and made several trips on the Thames against wind and tide at a reported speed of four miles an hour.

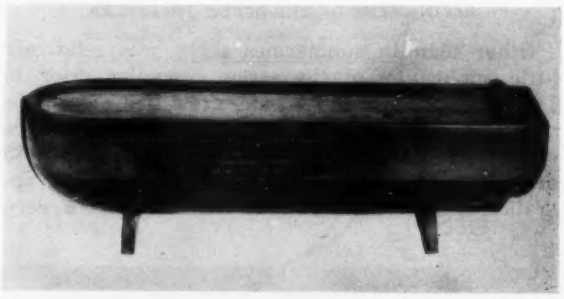

Figure 23. Fitch's first model with paddle-tracks

James Rumsey's English patent, granted in 1788, covered the water tube boiler and many fundamental principles of power plant economy as well as the steamboat itself. His United States patent was issued in 1791 and covered a device for propelling a boat by reaction of a stream of water forced out the stern by means of steam from a cylinder mounted parallel to the keel.

Nathan Read, of Warren, Massachusetts, was a Harvard graduate of 1781 and had studied medicine for a short period before his interest in steam navigation lured him away from a life as a doctor. He first occupied himself with the design of a light, compact boiler. By 1788 he had completed the drawings for what he called his *portable furnace boiler* to be used in steam carriages and steamboats.

Although Nathan Read built a steamboat in 1789 and advanced the idea of raising and lowering the paddles to accommodate different ship drafts, his greatest contribution to the field of ship propulsion was his boiler. This was a vertical, multi-tubular firebox design which remained in use for many years. Read was granted a patent for this boiler in 1791.

Other of Read's inventions were several forms of pumping engines and a plan for using the force of the tide, by means of reservoirs alternately filled and emptied, to produce a continuous stream of water. Read served as a congressman from 1800 to 1803 and later became the Chief Justice of the Court of Common Pleas of Hancock County, Maine.

Another New Englander who developed an interest in steam navigation during this period was Captain Samuel Morely of Connecticut. Morely built a steamboat propelled by a stern paddle-wheel. In 1790 this vessel made the trip from Hartford to New York City at a speed of five miles per hour. He demonstrated another of his boats a few years later at Philadelphia.

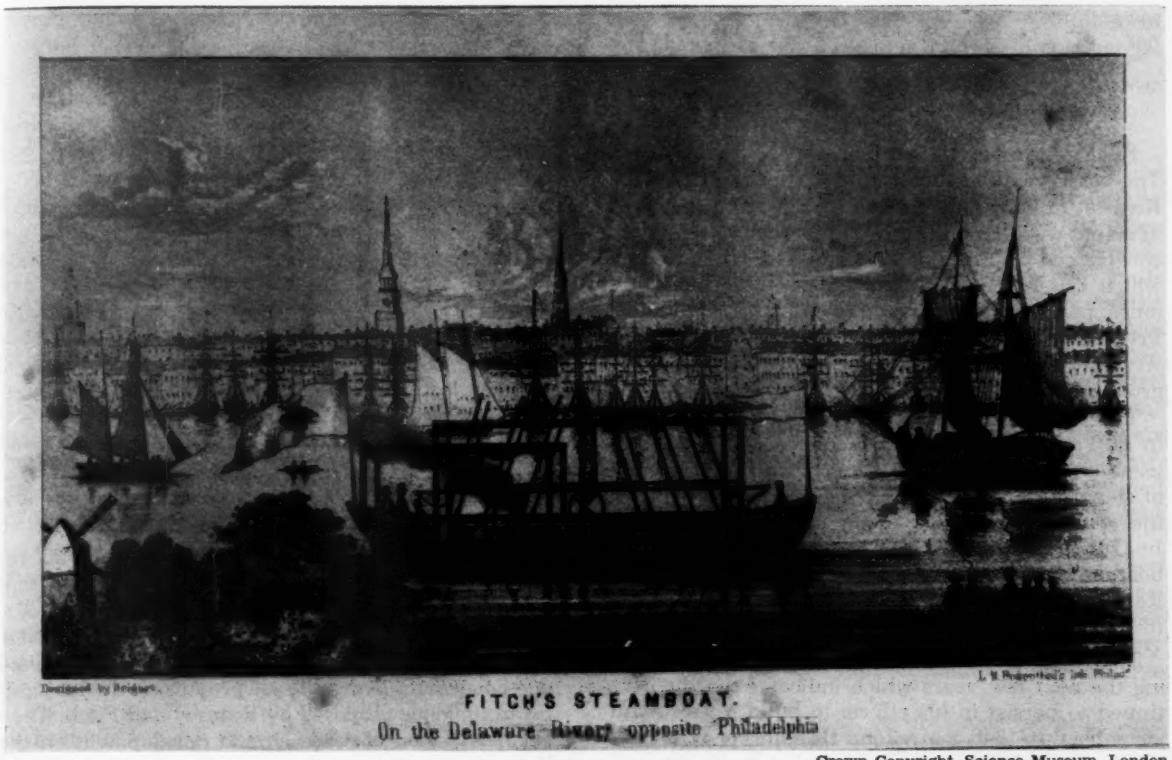

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Figure 24. Fitch's oar-driven steamboat

John Fitch, whom many claim as the inventor of the steamboat, was born in East Windsor, Connecticut in 1743. Like Rumsey he had few educational opportunities and at the age of 17 went to sea. He then worked as a clockmaker, a brassfounder, a silversmith, and during the American Revolution he served as a gunsmith for the American troops. Later, as a surveyor in the West, he was captured by Indians; after escaping he settled down in Warminster, Pennsylvania, and by 1785 he had completed his first model steamboat.

A picture of this model is given in Figure 23. As can be seen, the propulsive device was a pair of paddle-tracks mounted port and starboard each carrying light buckets. The buckets were rectangular plates pinned to the moving track and supported by flat bar back braces.

Fitch found that the buckets labored so hard underwater that he altered his design to provide six oars on each side of the boat. These oars were linked to the engine flywheel in such a manner that they were immersed in the water during the backward stroke and lifted out of the water for the forward stroke. Three oars on each side of the boat were in the water at all times thus supplying a continuous propulsive thrust.

Fitch published the following account of his boat in the *Columbian Magazine:*

Philadelphia, December 8, 1786

"To the Editor of the Columbian Magazine.

Sir: — The reason of my so long deferring to give you a description of the steamboat has been in some measure owing to the complication of the works, and an apprehension that a number of drafts would be necessary in order to show the powers of the machine as clearly as you would wish. But as I have not been able to hand you herewith such drafts, I can only give you the general principles. It is in several parts similar to the late improved steam engines in Europe, though there are some alterations. Our cylinder is to be horizontal, and the steam to work with equal force at each end. The mode by which we obtain what I take the liberty of terming a vacuum is, we believe, entirely new, as is also the method of letting the water into it, and throwing it off against the atmosphere without any friction. It is expected that the engine, which is a twelve-inch cylinder, will move with a clear force of eleven or twelve hundredweight after the frictions are deducted; this force is to act against a wheel of eighteen inches diameter. The piston is to move about three feet, and each vibration of the piston gives the axis about forty evolutions. Each evolution of the axis moves twelve oars or paddles, five and a half feet, which work perpendicularly, and are represented by the stroke of the paddle of a canoe. As six of the paddles are raised from the water six more are entered, and the two sets of paddles make their strokes about eleven feet in each evolution. The cranks of the axis act upon the paddles about one-third of their length from the lever end, on which part of the oar the whole force of the axis is applied. Our engine is placed in the boat about one third from the stern,

and both the action and reaction turn the wheel the same way.

"With the most perfect respect, sir, I beg leave to subscribe myself,

"Your very humble servant
"JOHN FITCH"

Fitch's hull was 45 feet long and 12 feet in beam. The vessel made a successful trial on the Delaware River at Philadelphia on August 22, 1787 as depicted in an old woodcut in Figure 24. Larger vessels were constructed by Fitch in 1788 and 1790, the latter of which was run as a passenger boat at a speed of 8 miles per hour between Philadelphia, Burlington, Trenton, Chester, and Wilmington. These boats were not a commercial success, and Fitch's backers gradually withdrew.

The United States patent granted to John Fitch in 1791 covered a propulsion device which was not used in any of his boats. It described the utilization of steam to pull water in at the bow and eject it at the stern, very similar to the designs of Rumsey. In 1793 John Fitch went to France to build a steamboat only to have his plans frustrated by the French Revolution. Penniless, he worked his passage back to New York.

There exists one account of Fitch's activities during the next few years which indicates that he continued to persist in his efforts to build a successful steamboat. In 1846, a Mr. John Hutchins of Williamsburgh, Long Island published a sketch of a steamboat with both a side paddle-wheel and screw propeller drive. He said that, as a lad, in the summer of 1796 or 1797, he had assisted Mr. Fitch in steering this boat on Collect Pond on Lower Manhattan Island. The boat was a common longboat, 18 feet in length and 6 feet in beam. She was steered at the bow when the propeller was in use. The boiler was a 10 or 12 gallon pot and the two clyinders were of wood, the piston rods being connected by a walking beam. Mr. Hutchins claimed that the boat made a speed of 6 miles per hour.

Apparently this vessel, if it ever existed, was also a failure. John Fitch retired to Bardstown, Kentucky where he took his own life by poison in 1798.

The last of the eighteenth century inventors who received United States patent recognition for his work was Colonel John Stevens. Stevens was a lawyer, born in New York in 1749, who had taken up residence in Hoboken, New Jersey. He witnessed Fitch's demonstration at Philadelphia in 1787, and at once became interested in steam propulsion which he pursued avidly for the next thirty years.

In 1789 Stevens petitioned the New York state legislature for the exclusive right to navigate the waters of that State by steam-propelled vessels. He was turned down, however, because the plans of the steamboat which he submitted did not meet the requirements of Congress. Stevens followed up his earlier petition in 1790 with a forceful request for

Lent to Science Museum, London by Bennet Woodcroft

Figure 25. Millar and Symington's catamaran

laws to protect American inventors. From his requests and suggestions stemmed the present patent system of the United States.

In 1791, when the first United States patents for steam propulsion were granted, Stevens obtained one covering a hydraulic jet propulsion device similar to the ones proposed by Rumsey and Fitch. Then began a period of research and development on the Stevens estate in Hoboken. He studied all the work of Watt, Read, Fitch, and Rumsey and conducted private experiments on many small boats with different types of propulsion systems.

Meanwhile in England the development of steam propelled vessels continued. In 1787 Patrick Millar of Dalswinton, Scotland built a twin-hulled vessel with a paddle-wheel at the stern. The engine for this craft was built by an ingenious mechanic, William Symington. The craft was fairly successful but extremely small.

Millar and Symington again collaborated in 1789 in the construction of a sixty foot vessel, also a catamaran. During trials on the Forth and Clyde Canal, this vessel went at the reported speed of seven miles an hour. It was called the *Double Pleasure Boat,* and is shown in Figure 25. Unfortunately the machinery proved to be too heavy for the hull and was removed ending Millar's marine experiments after an expenditure of $150,000. Symington, however, did not lose interest, and after the turn of the century achieved notable success.

While all of this fevered development of steam propelled vessels was taking place, countlesss arguments were in process regarding the claims of the many inventors who were working on essentially the same devices. The confusing patent legislation in no way helped the situation.

Nathan Read, for example, invented a logical method of raising and lowering paddle wheels to

permit them to operate at the optimum depth for varying drafts of the vessel on which they were mounted. Read, after submitting papers for a patent on this device, was told incorrectly by another inventor that the idea was already patented and he therefore retracted his claims to the idea.

The most bitter arguments arose between James Rumsey and John Fitch. The struggle for recognition and public favor between these two almost defied imagination. Rumsey published a pamphlet in 1788 denouncing Fitch, claiming that Fitch got his idea of a steamboat from a Captain Bedinger who in turn had learned all of the workings of Rumsey's boat. Three days later, Fitch published a stinging rebuttal stating that neither he nor Rumsey had the original idea but that he, Fitch, was certainly the first to put it to practical use.

It is unfortunate that these two ingenious men who were the same age and had similar backgrounds could not have pooled their knowledge and resources for the common good rather than to have devoted so much of their energy to fighting each other.

There seems to be no doubt that, in spite of the distances which separated the inventors of the day, pirating of ideas was commonplace. One of the most ubiquitous visitors and avid correspondents of the time was Robert Fulton. Although the claims of Fulton's piracy were deferred until after his success several years later, it was during the last years of the eighteenth century that his ideas were undergoing germination.

Fulton carried on an extensive correspondence with Lord Stanhope in England and visited him to discuss propulsion methods and engine development. He also visited Rumsey several times in England and carefully observed the construction of his *Columbia Maid*.

Captain Samuel Morely demonstrated one of his boats to Fulton in Philadelphia, and later claimed that Fulton had stolen all of his ideas. It seems to be fairly well established that Fulton actually did have an excellent opportunity to study Fitch's plans. When Fitch went to France he deposited his plans and specifications with the American Consul at L'Orient who in turn entrusted them to Robert Fulton for several months. And in Mr. Hutchin's account about Fitch's boat on Collect Pond he stated that Fulton had been aboard and that Fitch had explained to him the workings of all of the machinery.

Despite the frenzied rash of arguments which enveloped propulsion developments at the close of the eighteenth century, this was an era of great progress. During this period it was proved conclusively that a steam engine driven propulsion device could move a vessel through the water an average speed greater than that which could be achieved by animal power or sail. Furthermore, it was demonstrated that such schemes were practical and that there was a definite promise of commercial advantage in vessels so propelled.

CONCLUSION

Prior to 1800, almost every ship propulsion device known today had been either suggested or actually tried in full scale experiments. Of the paddle types the bow-wheel, stern wheel, side-wheels, submerged-wheels, and wheels mounted between twin hulls had been used; paddle-tracks had been tried and the feathering and adjustable-draft types of wheels had been proposed. Of the screw types, the Archimedian screw was perhaps the most frequently suggested but screw propellers of relatively modern configurations had been designed; surface propellers and air screws had been built, and single screw, twin screw, and triple screw installations had been recommended by various inventors; the retractable screw and steering screw were not unknown.

Many forms of hydraulic jet propulsion had been proposed including jets generated by steam pumps, internal paddles, and exploding gases. Various types of gas jets were mentioned as were a wide variety of locations on the hull of intake and discharge openings.

A modern design of vertical axis propeller had been proposed in the form of a mill drive. Ships had been propelled by duck feet, goose feet, oscillating umbrella cones, and vibrating boards. The forces of nature in the form of wind and water currents had been harnessed to drive ships through mechanical propulsion systems. And the forces developed in expanding and condensing steam had been put to work to drive propulsive mechanisms.

But, with all of this invention, development and experimentation, there was yet to evolve a mechanically propelled ship which could be termed a commercial success. In spite of the many thousands of dollars which had been invested in propulsion schemes there was no mechanically propelled vessel which saw sufficient cargo or passenger service to reward its inventor financially. Few of the inventors who applied their talents and enthusiasm to the development of means for driving a ship through the water realized anything from it but the satisfaction of having contributed to the advancement of science.

However, at the turn of the century the time was ripe for notable achievements in this field. All of the necessary tools for building a workable steamboat were at hand. Years of experience with all sorts of failures provided a wealth of valuable knowledge to this infant technology. It remained only for someone who had assimilated all of the information regarding past successes and failures to apply this knowledge to the design and construction of a really practical, mechanically propelled ship.

ACKNOWLEDGEMENTS

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Some of the activities of the ocean bottom exploring vessel known as the bathyscaph have been described in a recent article in "Scientific American" (April 1958). Designed by August Piccard, the vessel is essentially a pressure resistant sphere of about six and one-half feet in diameter and three and one-half inches thickness, supported by a non-pressure vessel containing a buoyant liquid—gasoline in this case. This vessel, having the same pressure inside and out, is constructed of about fifteen pound steel plate. Vertical control is achieved by control of lead shot ballast and by the ability to displace a part of the gasoline with salt water.

The bathyscaph is capable of diving to 20,000 feet and has exceeded 10,000 feet in reported dives. Important data has been collected in the fields of marine biology, underwater acoustics, geology and oceanography.

Scientific equipment carried in the sphere includes mercury-vapor flood lamps, a camera with an electronic flash and an echo-sounder. A directed sound telephone provides communication with the surface as well as providing a means for determining the depth. This is accomplished by measurement of the round trip time of sound waves from the vessel to the surface. An oxygen supply sufficient for forty-eight hours is provided for the two-man crew.

COMMANDER BERNARD M. KASSELL, USN

MARINE ENGINEERING NOTES FROM THE SOVIET PRESS

THE AUTHOR

enlisted in the Navy in 1931, and has served continuously since that time. He attended Cornell University and Maryland University, obtaining his B.S. degree in Military Science from the latter institute. He has had a wide range of duty assignments, including tours as Engineer Officer and Repair Officer on various ships and tenders. He is currently stationed in Port Lyautey, Morocco as Commander Military Sea Transport Service, Morocco. The materials contained in this article have been taken from Russian language publications. The translations are the work of the author.

Atomic Icebreaker

5 December 1957 was Constitution Day in the Soviet Union. It was also the day selected by Soviet officials to launch *Lenin*, the atomic icebreaker reported on earlier in the November issue of the JOURNAL.

The launching was officially announced as having taken place before thousands of spectators who watched the hull, encased in a cradle of some type, slide into the waters of the Neva River in Leningrad. The story accompanying the launching announcement stated that only the first stage of the construction had been completed and that much work remained to be done "but the first icebreaker in the world with an atomic powered propulsion installation will be completed."

The propulsion plant will consist of a powerful nuclear reactor, located in an amidships compartment, connected with a steam generator, turbo-generators and main drive electric motors developing 44,000-hp and driving the vessel at 18-knots. The Kirov Works in Leningrad has been cited as the manufacturer of the turbines, the first of which are reported already installed. Late in November the last of the turbines was under test. It is also reported that the largest "engine" will weigh 175 tons and that "the other two engines" will weigh 103 tons each.

Another Leningrad plant, the "Elektrosila" Works, has been noted as the builder of the first two generators of the five to be installed. These units are rated at 1250-kva and are for lighting and power, the latter service to be three phase.

Machine shops in the Kramatorsk Works completed the first of four drive shafts, with the part listed as 12-meters in length and weighing 25-tons.

The master of the vessel has already been assigned, as have certain other key personnel. Captain P. A. Ponomarev is an experienced hand in the Arctic, having participated as 1st Mate in the icebreaker *Krasin* voyage to the Arctic in 1926. He also took part in the rescue work connected with the rescue of Nobile and the other personnel from the Italian dirigible *Italie*. Ponomarev points out that even today, despite the advances made and despite the aids, such as aviation, radio, automatic drifting stations, radio direction finders, radar, and fathometers, sailing on the Northern Sea Route still presents the mariner with considerable difficulties.

By the end of 1957 personnel assigned to the ves-

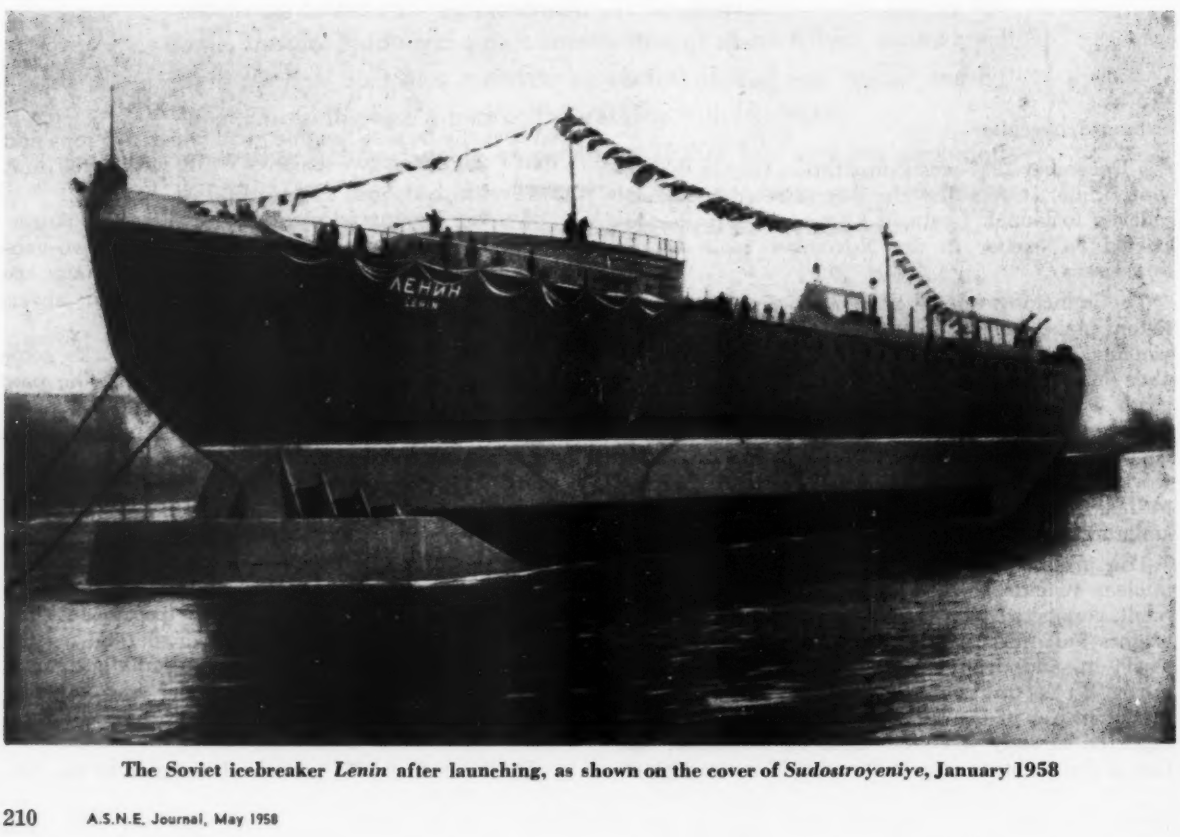
Launching of the Atomic Icebreaker *Lenin*

sel numbered twenty and included Chief Engineer K. K. Dolgopolov, and engineers Z. G. Rusakov, A. V. Neypokoyev, and G. V. Garshin.

Winter Ship Repair

The ship repair program for the river fleet for the winter 1957-58 was drawn up and assigned in an order dated 20 August 1957. The success with which the ship repair yards meet this order will, in large measure, determine the performance of the river fleet during the season which has already begun. The usual pattern of repair is for the river fleet to report to laying-up points, called "zatons," or to repair bases or yards somewhere within the operational sector of the river to which individual units in the fleet are assigned. Here the repair work may be done by yard personnel, ship's force, or a combination of the two. Frequently repairs are hampered by lack of supplies, inadequacy of transport and/or lack of facilities. However, as the orders are promulgated well in advance, usually, of actual laying-up, a considerable measure of success is usually found in the final round-up of statistics. Too, the orders will encompass directives for over-all programs. For example, the order cited the fact that the program was such as to reduce the number of self-propelled vessels sailing under restrictions of one sort or another by 3 to 8 percent and a similar reduction, between 2 and 4 percent, was required for non self-propelled units. A considerable amount of work was involved in refitting 270 vessels, totaling 84,000-hp, for operation on liquid fuel. The Volga Combined Steamship Line was directed to strengthen and refit 130 self-propelled units so as to qualify them for class "O" or "Lake" use, while a similar measure applied to 172 barges assigned to the Kama Steamship Line.

Some 150 tugs and 230 barges were to be refitted so as to be usable for pushing rather than towing in the usual sense. This requirement is a continuation of expansion of the pushing method in the Soviet Union, a method which first came in to use in the '30's and which program drew on United States



The Soviet icebreaker *Lenin* after launching, as shown on the cover of *Sudostroyeniye*, January 1958

efforts along the same lines at that time and since. The system thus is not a new one, but it is interesting to note that despite the fact that pushing was known on the Danube as early as 1927, it was US, rather than European methods, which turned out to be the more practical for Soviet rivers.

Getting back to ship repair, it is a peculiarity of this year's program that 13 of the river steamship lines have assigned their self-propelled units to specific repair-operations bases and shops for maintenance. This system has, according to present accounts, enabled the outfits concerned to make up master repair lists for 14 different types of vessels, an innovation which is said to have simplified repair work considerably.

This system, it is hoped, will prevent a recurrence of last year's results when, in the Volga Tanker Steamship Line and the Volga Combined Steamship Line alone, over 300,000 tons of shipping was still undergoing repair after the season had opened. In January the first of these two lines was still in difficulties, however, charged with having failed to send 50 barges used in carrying petroleum in to the "III International" Shipyard for needed repairs. The barges had not been unloaded in time and were caught by the ice. Further, the line, as of 1 February was accused of having failed to clean up over 300,000 tons of barge capacity prior to repair.

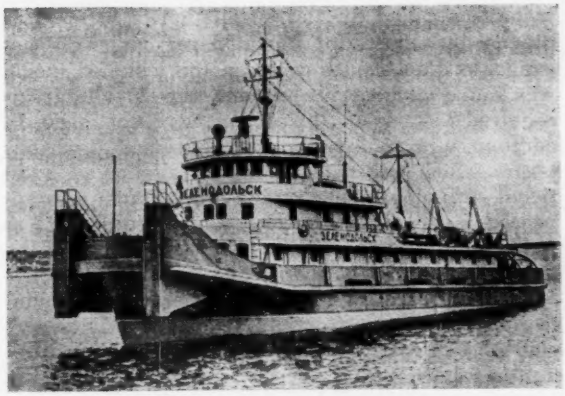
A reasonable view of the ability of Soviet crews is apparent from the fact that this winter found over 1,500 vessels being repaired by their own crews, the volume of repair work being accomplished a reported 300 percent over last year. This method of repair is still not used universally, however, for the Northern River Steamship Line is reported to have committed not more than 20 percent of its crews to such work. The Ob Steamship Line is using the crews of but 80 vessels of the 520 in repair while the Yenisey Steamship Line has assigned ship's crews to work on only 36 of its 500 repairing vessels.

The Tug-Pusher "Zelenodolsk"

In line with the development of the pushing method of moving barges along Soviet rivers, we find that, in mid-July 1957 a new type of twin-screw, diesel propelled, tug-pusher was placed in service with the Volga Combined Steamship Line.

The vessel, named *Zelenodolsk* (see cut), was built in the M. Gorkiy Shipyard in accordance with Project 749, developed by the Central Design Bureau of the Ministry for the Shipbuilding Industry (since 14 December 1957 redesignated as the State Committee for Shipbuilding Technology). Considered as the class leader, the vessel is rated at 1200-hp and is classed in the Register of the USSR under the designator "O" for "Lake" use as a tug-pusher.

Among the unusual design features is lack of a rudder. Two directional hoods have been installed around the propellers and a stabilizing device, not expanded upon, is included so as to provide the vessel with good maneuvering qualities in both the ahead and astern direction. The twin bow bumper arrangement is an integral part of the hull and permits pushing operations in relatively high wave conditions. A powerful stern anchor installation permits bringing the tow to anchor when headed downstream without the need to turn the tow. Both the flying bridge and the wheelhouse are of sufficient height to enable the vessel's pilot to make visual observations when necessary. The vessel is equipped with a STVOR-type radar (See "Notes" in the November, 1957, JOURNAL), giving the vessel an all-weather capability.



New tug-pusher *Zelenodolsk*

Certain of the characteristics of the vessel follow:

Length over-all	**40.93 meters**
Designed length	**39.47 meters**
Beam, with rubbing strakes	**9.48 meters**
Beam, designed	**9.00 meters**
Height of side	**3.50 meters**
Displacement empty	**378 tons**
Displacement, one day store fuel and lube, ballasted	**438 tons**
Displacement, 15 days fuel	**479 tons**
Displacement, maximum	**503 tons**
Draft, mean, max displacement	**2.22 meters**
Main Engines, 2 x 600 hp, 300 rpm	

Trials were conducted with two barges of Project 462 design, each carrying some 1,900 metric tons of cargo, and the group registered 16.8-km/hour. An additional barge of 1,800 metric tons capacity, empty, was added to the group whereupon the speed attained fell to 15.8-km/hour. However, unencumbered the pusher clocked 21-km/hour. With the three barges the diameter of a circle during a 360° turn measured 560-meters, while alone the vessel turns in approximately its own length.

During acceptance trials in the Mayna-Ulyanovsk area, with winds of 16.5-meters/second blowing, wave heights were recorded as 1.5-meters. Under these conditions underway speed fell off 2-km/hour, so that the trial course of 26-km was covered in one hour 52 minutes, or at a rate of some 13.9-km/hour.

The most serious difficulties encountered during trials were with the 6DR 30/50 main engines. Orig-

inal plans called for the installation of 6DR 36/45 diesels, but these, for unstated reasons, were not available. Fuel consumption in the installed model was found to be excessive and certain alterations required to improve this defect were not made. In addition, unexpected vibration developed at various places which will require the installation of additional stiffening in the engine area. Faults also appeared in the remote engine control equipment as well as in the engine order system. The design of the flying bridge and of the bridge itself, while originally noted as being of adequate height, was found to limit visibility in certain sectors and it is now planned to correct this fault during serial construction to follow.

Original plans called for provision for removal of the diesel generators when unit repairs were required by the use of shore cranes. Soft patches in the decks simplified the procedure. However, it was found that during construction the cable runs had been laid in in such a manner as to make unit removal of the generators an extremely complicated task. The hand steering arrangement was designed for operation by two men but it was found that a pull of 60-kilograms, rather than the designed 40-kilograms, was required. Unstated defects developed in the electrical steering system as well.

Later vessels in the class will, apparently, incorporate a stern ballast tank to bring the stern down and increase the differential *vis a vis* the bow when the vessel is fully loaded. Hull work in future units will be of greater strength in order to permit the tugs to operate in young ice and to bring ships in and out of their wintering places prior to complete breakup of the ice.

Yenisey Steamship Line Augmentation

In 1958 it is expected that the fleet assigned to the Line will be increased by 23 tugs and 12 dry-cargo diesels, Class "O" (Lake-type), as well as by 17 steel non self-propelled units, of which ten will be lighters suitable for use on lakes and in the open sea. In addition, the Line will receive four passenger ships using both diesel-electric and diesel propulsion, two refrigerator vessels, and eight landing stages.

Conference Roundup

The winter season is the conference season for people connected with ships and shipbuilding in the Soviet Union. Results and failures, as well as new developments, are reported and it is from papers and speeches delivered at these conferences that new ideas are generated.

Late in November a scientific-technical conference opened in Leningrad to deal with questions of design and construction of merchant ships. One of the Deputy Ministers for the Maritime Fleet, A. Kolesnichenko, opened the meeting and outlined for the assembled delegates the tasks assigned to the shipbuilding industry by the XXth Congress of the Communist Party. Delegates representing various ministries, scientific-technical bodies, planning and design organizations attached to the maritime fleet and to the shipbuilding industry, as well as representatives from individual steamship companies, were present at the meeting which was held in the Admiral S. O. Makarov Higher Marine Engineering School building.

Kolesnichenko was followed to the rostrum by the Maritime Fleet spokesman, N. Byikov and by N. Golubyev for the shipbuilding industry. Both speakers devoted their time to explaining the need for development of plans for building a fleet for the future—10 to 15 years from now. The speakers made the point that basic work is needed to improve design and research work as it pertains to the maritime fleet. Papers were delivered on subjects such as modern propulsion plants for merchant ships, standardization, modern marine diesel engines, automation on merchant ships now and in the future, and the need to improve the use of ships in service. Stress was laid on the need for modernization of the rules for building ships, an issue pointed out in the November JOURNAL, page 729.

The conference concluded on 4 December and, during the final, plenary session the delegates made a number of important, but undisclosed, recommendations for improving the scientific-research and design work in the field of shipbuilding in order to build highly effective merchant ships in the future.

As was noted, no specific recommendations were published. However, the conference appears to have generated a series of articles which reflect these recommendations, for they indicate the concern of the planners for the future. Various writers point out that in recent years the merchant fleet has obtained a large number of "serial" ships of various types. The difficulty now is the realization that despite their apparent moderninity, these vessels do not meet today's requirements in such important indices as carrying capacity, engine power, and speed. End results of what is stated to be poor planning have been higher than anticipated costs for both cargo and passenger transportation. Designers have been castigated for neglecting to plan for the future with the scientific-research institutes, the shipbuilders, the machine builders and the electrical industry. The designers have been specifically charged with the faults which have cropped up in the *Dneproges, Kazbek, Oleg Koshevoy* and other classes. Many of these faults have already been noted for readers of the JOURNAL in the May and November 1957 issues.

Captain Tkachenko and Chief Engineer Zilbershteyn of the tanker *Ashkhabad,* a *Kazbek*-class tanker built in 1954, have pointed out that their ship, although built to operate for 20 to 25 years, is already obsolete as compared with modern day tankers built elsewhere and in fact costs 2 to 3

times more to operate than other classes of tankers.

At the same time engine builders from such plants as the Kirov Works in Leningrad, the "Russkiy Dizel" Works, and the Bryansk Machine Building Works have reported their readiness to provide merchant ships with reliable and economical propulsion installations. The Kirov Works claims to have a gas turbine installation in the sketch plan, or first, stage of design. "Russkiy Dizel" reported having done a considerable amount of work on improving the operation of the 8DR 43/61 engine, the model engine, it will be recalled, used for main propulsion in the *Kazbek*-class tankers and which, from all accounts, has been unsatisfactory. Bryansk has indicated the ability to build a slow-speed internal combustion engine, but the technical documents connected with the construction have not arrived in the plant. In addition, the same Works reported available capacity to build new marine engines but that thus far progress has not reached beyond the talk stage.

Many other comments have appeared and include discussions on improving living conditions for crews, the introduction of standard prices for ships under construction, the building of model basins and experimental bases, the development of new methodology for determination of best speeds for ships, wider specialization for design bureaus and shipyards, and more careful study of lead ships in any program before serial production is undertaken.

The same general themes are encountered in the reports of virtually all conferences reported. Late in January an inter-basin conference was held in Perm, the chief topic that of thermal-technical operations in the Kama, Volga Combined, Irtyish and Volga Don steamship lines. This conference drew representatives from the Institute for Transportation Problems of the Academy of Sciences of the USSR, the Central Scientific-Research Institute for the River Fleet, as well as the delegates from the individual steamship lines. The general theme was thermal-technical work and fuel use in 1957. Much interest was generated by the presentation made by Engineer Shumkov of the Volga district, who spoke on the results of the use aboard the steamer *Mashuk* of his photo-electrically operated automatic unit for controlling the feeding of marine boilers. Considerable attention was devoted to the results of tests of a new design firebox used aboard vessels assigned to the Kama Steamship Line, to the use of water tube boilers, and to operations using liquid fuel. The conferees expressed themselves as favoring wider introduction of the various features in the river fleets.

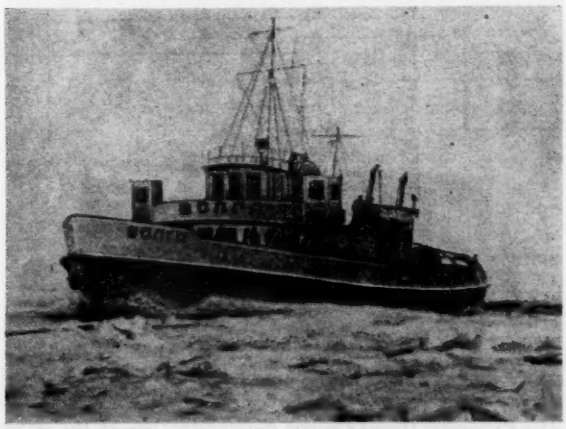
Finally, Leningrad was the site of a similar inter-basin conference late in February. This meeting was attended by representatives of the Northern, Northwestern, Pechora, Moscow, White Sea-Onega, Kama and Western steamship lines, basin route administrations, the Baltic Steamship Company, the Moscow Canal Administration and various scientific-research institutes. Papers were delivered on the status of thermal techniques in use, fuel utilization, the work of the thermal-technical groups, methods for standardization of fuel use, the need for the introduction of the most effective modernization measures, and the introduction of new techniques. Discussions of the results of field tests of automatic combustion control equipment, water treatment and water control measures, and the processes for removal of oil from condensate attracted lively discussion on the part of the conferees.

Latvian Steamship Company Announced

A new steamship company, the Latvian, has been formed from a subordinate regional administration previously attached to the Baltic Steamship Company. While the reasons for its formation include the usual ones, such as economic rationalization, it is recalled that the new company had, in the early 1950's, been a separate entity which had been absorbed into the Baltic Steamship Company, its functions being divided between Riga and Tallin regional administrations. The new company will control the ports of Riga, Lepayda and Ventspil, as well as the ship repair yard and shops in Riga and the Baltic Sea Route Administration, the latter a service organization concerned with buoyage, dredging work and the like. Personnel for the company will come from the Riga Nautical School and the company will engage in both foreign and domestic trade. Initially, ten cargo vessels have been assigned, including the relatively new *Arzamas, Kotlas* and *Balashov*.

Electric Drive

Further comment on the use of electric drive on ships for use on inland waterways has been found in remarks attributed to Professor V. L. Lyichkovskiy. The professor points out that the Volga River is the training ground for electric drive installations and notes that the first vessels built in recent years using electric drive are the icebreaker-tugs *Volga*



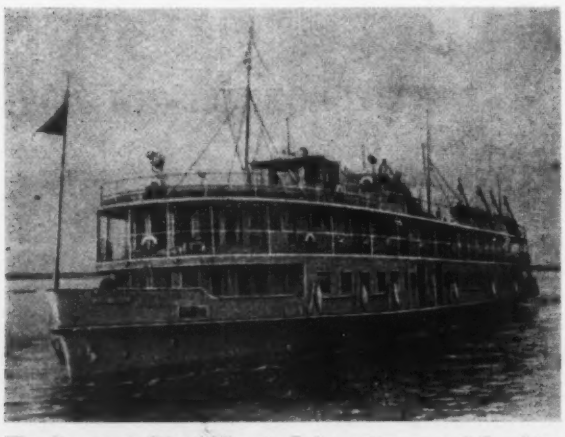
The Diesel-Electric River Icebreaker *Volga*

and *Don*. The two were built in 1950 in the A. A. Zhdanov Shipyard in Sormovo and were equipped with two diesel-generator units utilizing the D50-type engine, rated at 900-hp, and direct current. Starting was accomplished by the use of batteries. The generators were rated at 700-kw, 700-volts, 720-rpm and the installation figured down to 26-kg/hp. The drive motors were rated at 480-kw, 700-volts, 330-rpm, and were the closed type with a closed cooling system; the entire installation weighing 23-kg/hp. Six years of operation were studied to arrive at the conclusion that the vessels had proved their utility, despite certain shortcomings. Included in reported faults are: inability to operate both motors from one generator during repair periods, or when moving downstream without a tow; poor control at reduced speeds; lack of power for certain operations.

Yet another class providing data for analysis is the Czechoslovakian-built *Rossiya*-class passenger vessel. The first unit appeared on the Volga in 1952 and has been reported as powered by two direct current diesel-generators rated at 400-hp each. The 4-cycle engines turned up 550-rpm and the main generators, rated at 273-kw, 490-volts, 500-rpm, supplied the drive motors which, in turn, were rated at 250-kw, 487-volts, at 240-rpm.

Based, perhaps, on experience in the operation of those vessels already cited, or perhaps because of the belief that operation of diesel-electric drive vessels is completely feasible on all inland waterways, we find additional units utilizing this means of propulsion coming into service.

In mid-October the "Krasnoye Sormovo" Shipyard (also referred to as the A. A. Zhdanov Shipyard in Sormovo) reported the trials of *Lenin*, a new diesel-electric powered passenger vessel for the river fleet. Not to be confused with the atomic icebreaker of the same name, this vessel, claimed as largest passenger vessel on the country's rivers, is 121.4-meters long, has a beam of 16.8-meters and displaces 2,235 tons. The three diesel-generators installed for propulsion develop 2,250-hp and are reported as driving the vessel at 25-km/hour. The first of a series of triple-screw units, the second in the class has been listed as *Sovetskiy Soyuz*, these passenger carriers are outfitted with modern conveniences of all types, including telephones and air conditioning.



The Passenger Diesel-Electric *Belorussiya*, one of the ships in the *Rossiya* series

The fourth in a series of diesel-electric ferries, *Zapolyarnyiy*, built in the Arkhangelsk area, completed a transfer from the building area to Rostov, on the Don River, early in December. This appears to be the second such unit to be sent around the Soviet Union to an ultimate destination of Stalingrad on the Volga River. Included in the traverse is passage through the Volga-Don Canal. Two sisters are assigned to carry railroad trains across Kerch Straits in the Black-Azov seas area. Interest in rail ferries is not new in the Soviet Union and was the subject of a visit by a delegation of Soviet engineers, led by M. Volkov, Chief Engineer of the Caspian Sea Planning Commission, to Denmark late in 1957. The group admittedly was out to study Danish methods in the building and use of rail ferries for ultimate application to the operation of the first rail ferry to be placed in service this year between Baku and Krasnovodsk. The group, in very nearly three weeks of visiting. took in many Danish shipyards and traveled on all the ferry crossings in use. Volkov claimed to have gained more from a half hour chat with the chief engineer of one of the ferries than he had been able to gain from hours of talk with officials of various of the firms hosting the visitors.

A series of two known straight diesel ferries, *Syiprus* and *Suurupi*, have been operating among the islands off the Estonian coast for over a year now. but the Leningrad-built vessels appear to be outclassed by diesel-electric craft for the same use in Soviet eyes.

Known additions of diesel-electric propelled units include the whale catchers reported on in the November issue of the JOURNAL, a class which appears slated for increased production as a result of the report that the "Uralelektroapparat" Works had completed the construction of main drive alternating current generators rated at 760-kw for ships to be assigned to the SLAVA whaling flotilla. Included was reference to the shipment of another 35 main drive electrical generators by the Sverdlovsk builders. It would thus appear that the original contract, whereby the Kharkov Works for Diesel Locomotive Electrical Equipment built direct current generators of the same rated capacity, has been expanded to include the Sverdlovsk plant mentioned above and, further, that the design may have been changed to utilize alternating rather than direct, current on future whale catchers. The present contract, apparently made up of 43 units, is one short of enough machines for eleven vessels, in addition to the three previously reported on and which have been in op-

eration for the past year. Suggested here is retirement of the relatively slow and ancient whale catchers assigned to SLAVA and replacement by new, modern and efficient units.

Propulsion Problems

One of the mainstays of the river fleet is the Type 3D6 diesel engine, rated at 150-hp. Used singly it powers the ubiquitous *Moskvich,* the passenger vessel which has proven to be the workhorse in the fleet, while in tandem it powers tugs and the larger passenger vessels. Overhaul of the engine was originally set for about 2000 hours of operation, but design changes and innovations on the part of enterprising engineers on individual vessels resulted in an extension of the operating time to as high as 10,000 hours.

Unit repairs were established as the best method of handling this vital function and specific shipyards were outfitted with diesel overhaul shops to accomplish the work. Engines were lifted out and replaced with rebuilt engines as necessary. Only recently, however, has it become apparent that the 3D6 has not been as reliable and efficient as was originally reported.

The major fault, but hardly a new one to diesel engineers, has been the discovery of rather widespread corrosion of liners and blocks on the cooling water side. Specifically, in 1955 in the Vologda Regional Administration of the Northern River Steamship Line, of 37 engines examined, 20 blocks and 150 liners required replacement. It appears that the various remedies used, such as the use of inhibitors and the use of distilled water, failed. It was not until the closed cooling system was replaced with an open, circulating type so that a temperature differential was established between inlet and discharge points that the difficulty was overcome. Other difficulties were experienced with warping of the hull and of the exhaust piping as a result of overheating. The cracks, which occurred at the points where the exhaust piping entered the water, were serious enough to cause ships to be laid up. In addition, the gases entered the crew spaces, causing serious inconvenience. This difficulty was overcome by exhausting above the waterline and by-passing some of the gases into a system for heating the individual vessels.

In the face of the foregoing, the Limenda Shipyard, builder of 300-hp tug-pushers, was severely criticized for having failed to eliminate the defects during the building period. Instead the Vologda Shipyard made the necessary alterations to the new units in 1957.

The propulsion installation in the *Pervomaysk*-class ore carrier, a class ordinarily used in the Azov Sea Regional Administration of the Black Sea Steamship Company, is once again the subject of concern to the operators. The class is Polish-built, 1946 GRT, coal fired and variously reported making 6½ to 11½ knots, depending on the condition of the individual vessel. Some twenty *Pervomaysk's* were delivered for use on the coal-ore run in the Azov Sea area. In addition to being poor sea keepers, the vessels were found to have inadequate ballast tanks and vibrated so badly that cracks appeared along the hatch coamings when full power was applied.

In addition, personnel of the engineering department in the Regional Administration claim that the boilers cannot provide the needed steam to operate the main and auxiliary plants installed. The layout is such as to make operation awkward and inconvenient. This combination of poor operational features and design faults resulted in decisions to modernize the vessels by converting them to oil burners and effecting certain structural changes.

Perhaps the most successful of the class is the *Makeyevka,* which, as a result of careful attention to operating procedures, has been able to utilize installed horsepower at somewhere near design rating. The vessel is reported capable of making 9.8-knots at 112-rpm and has steamed her boilers over 2000 hours since last cleaning, compared with a standard of 1200 hours as normal. However, it has also been reported that the Ministry for the Maritime Fleet has ordered the class taken off the run, to be replaced by 3,000-ton lighters. It is pointed out that a lighter only needs a 17 man crew, as compared with 43 men in the crew of a class vessel. In addition lighterage charges run 6.93 rubles per ton as compared with 9.45 rubles by ship.

New Construction

According to the trade agreement drawn up between Finland and the Soviet Union, Finland was to deliver a 7,800 metric ton capacity freighter in each of the years 1956 and 1957. The 1957 addition to the Soviet merchant fleet appears to be the motorship *Frolovo* which, in December, was loading for the Middle East in Odessa.

A Leningrad shipyard is reported to have built a new, seagoing fire boat equipped with powerful pumps which, in one hour, can deliver over one thousand tons of water a distance of 70 meters. The fire boat can, in a manner not specified, operate in water covered with burning oil without danger. The first unit was tested successfully and was sent to the Caspian Sea for use in the vicinity of the coastal petroleum industries. Several more vessels of the same type, and for the same destination, will be built in 1958.

The motorship *Mgla* has been delivered to the Hydro-meteorological Observatory for the Black and Azov Seas. The new vessel, classed as a hydrographic ship, will be used for deep-water observations and its first voyage was to have taken place about mid-December in connection with observations to be made for the International Geophysical Year program.

Azimut, a new school ship, was reported in service early this year with the Odessa Higher Nautical

School. The vessel is equipped with the latest electrical and radio-navigation equipment and will enable students to train at sea at various aspects of studies which had previously been done ashore for lack of an afloat facility.

The latest addition to the Soviet icebreaker fleet, the diesel-electric *Indigirka*, sister of *Ob* and *Lena*, entered the port of Arkhangelsk in January. The vessel broke her way into the harbor to pick up a cargo of cellulose for the Baltic. *Indigirka* was selected because her use was considered to be cheaper than sending the cargo overland by rail. The vessel had departed Murmansk, picked up 4,000 metric tons of coal in Spitzbergen and after loading in Arkhangelsk had proceeded to Antwerp under command of Captain A. F. Pinezhaninov, a participant in the first Antarctic expedition on the *Ob*.

A new fishing vessel, RR-1307, was reported as having arrived in Baku early in January. The East Germany-built fish refrigerator had made the passage to the Caspian via the Mediterranean and Black seas and, since the last part of the voyage required passage via the Volga-Don Canal and the Volga River, such passage was concluded prior to the winter freeze up. The vessel is equipped with radar, radio direction finder, fathometer, gyro compass and a course recorder which logs the course of the vessel as well as controls the rudder.

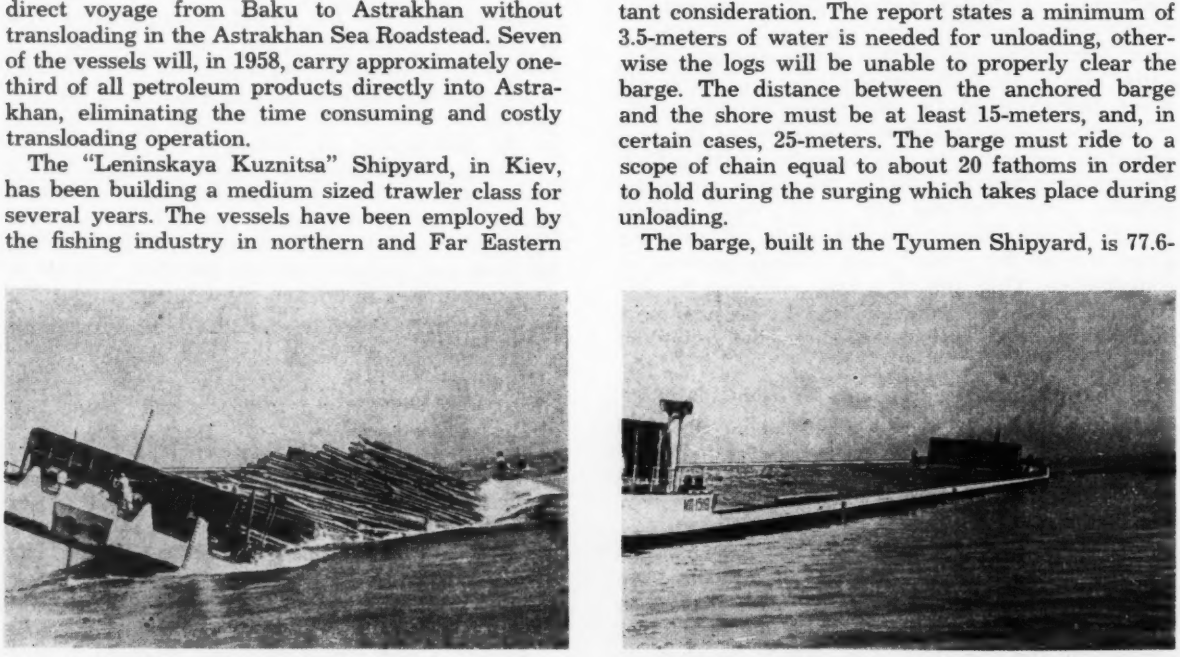
Two previously unreported *Oleg Koshevoy*-class shallow draft tankers were pictured in Baku late in December. The two, *Bolshevik N. Narimanov* and *Bolshevik B. Sardarov*, bring to ten the number of such tankers in operation on the Caspian. One of the class, *Ivan Zemnukhov*, recently made the first direct voyage from Baku to Astrakhan without transloading in the Astrakhan Sea Roadstead. Seven of the vessels will, in 1958, carry approximately one-third of all petroleum products directly into Astrakhan, eliminating the time consuming and costly transloading operation.

The "Leninskaya Kuznitsa" Shipyard, in Kiev, has been building a medium sized trawler class for several years. The vessels have been employed by the fishing industry in northern and Far Eastern waters. An improved version of this class, designed by Stalin prize winner A. Baybakov, the first of which has been named *Bologoye*, will supersede the original design. *Bologoye*, placed in service late in 1957, is classed as a seagoing, single screw, two masted craft with an all-welded steel hull. Basic dimensions are: length 43.4 meters; beam 8 meters. Installed equipment includes a Freon refrigeration plant for chilling the fish receiving holds, radio receiver and transmitter, radar, and electrically driven trawl winches. It has been announced that eight more of the class were to be delivered prior to the end of 1957.

The carrying of timber occupies an important place in the economy of water transportation in the Soviet Union, particularly on the rivers, where rafting or barging is the only practical method of transporting the logs. At the same time, because of the relative inaccessibility of many of the loading and unloading points, costs for handling the timber have been excessive, even by Soviet standards. Suggestions of methods to overcome the difficulties have included one way which appears to have proven successful—a self-dumping timber barge.

Originally suggested in 1952 by A. N. Lukovitskiy, a barge skipper attached to the Irtyish Steamship Line, the outcome incorporates a row of ballast tanks along one side which, when flooded, place an angle of list of some ten degrees on the barge and the logs, stowed athwartships on a series of other logs laid fore and aft, roll off into the water at the timber roadstead unloading point. Since most of the points where unloading operations take place are within river boundaries, water depth is an important consideration. The report states a minimum of 3.5-meters of water is needed for unloading, otherwise the logs will be unable to properly clear the barge. The distance between the anchored barge and the shore must be at least 15-meters, and, in certain cases, 25-meters. The barge must ride to a scope of chain equal to about 20 fathoms in order to hold during the surging which takes place during unloading.

The barge, built in the Tyumen Shipyard, is 77.6-



Self-Dumping timber barge shown (a) at moment dumping commenced and (b) the barge after dumping

meters in length, 15-meters in beam and, with 1700 metric tons of cargo on board, draws 2-meters. There are six transverse, and one main longitudinal, bulkheads dividing the barge into 10 watertight compartments which can be used to carry liquid fuel. The ballast system consists of the five wing tanks along the port side. Each tank has its own ballast valve and all tanks are interconnected via limber holes cut in the upper section of the transverse bulkheads.

During trials it was found that the tanks, the valves for which are controlled from the midships tank fore and aft, flooded in about 30 minutes and when the list had reached about 11 degrees, the cargo rolled off in about 10 seconds. List remaining after cargo was discharged was some seven degrees and the tug used to tow the barge from the area experienced no difficulty in handling the unit. Clearing the tanks is reported to take from 40 to 50 minutes.

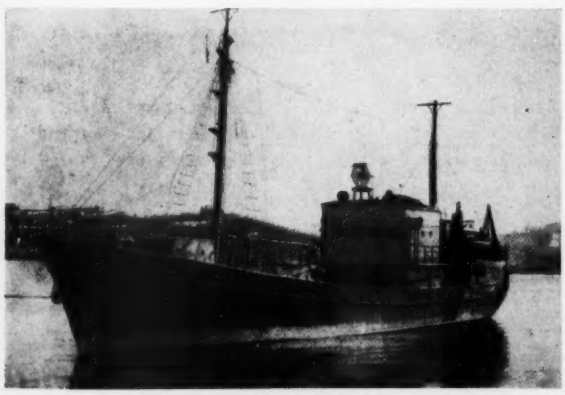
Aktyubinsk-Class Refrigerators

Additional information on this class of diesel-electric has recently become available to supplement the data presented in the November issue of the JOURNAL, page 728. Salient features of the vessel are:

Length betewen perpendiculars ...	118.0-meters
Beam	16.8-meters
Draft to marks	7.5-meters
Displacement, full and down	10,250 tons
Main diesel-generators	4 x 1250 kw
RPM, full speed	135
Speed, in ballast	18.5 knots

Diesels installed for driving the main generators are rated at 1800-ehp at 810-rpm.

The refrigeration installations in the class are the first Soviet marine-type ammonia plants to be built and are classed as fully automatic installations. The machinery is installed in its own compartment on an upper deck and includes three two stage compressors Mark MADS-150, two of which are required in operation to service the bow and stern groups of boxes, with the third in reserve.



Modernized trawler *Bologoye*

While the installation is able to meet Register requirements, it is pointed out that from the standpoint of weight and size, for shipboard use, they are not entirely satisfactory. Designers are urged to look into the problem and present, for the rapidly expanding refrigerator fleet of the Soviet Union, a more economical and smaller sized package.

Tanker Developments

In mid-December it was announced that a new tanker *Stanislav* had successfully completed her underway trials and, at about the same time it was also announced that yet another new tanker, *Zhitomir,* had departed the Kherson Shipyard.

The former is the 16th of the *Kazbek*-class to be built in the Admiralty Shipyard in Leningrad and changes in the design have been reported for this vessel. The forward bulkhead of the 'midships superstructure was, at the lower levels, brought forward to match the forward bulkhead of the navigation bridge. In addition to improving the looks of the ship, it is stated that additional space was obtained for the wardroom, two cabins and several passageways. *Stanislav* was laid down in December 1956, launched on 27 April 1957 and was placed in service at the end of 1957.

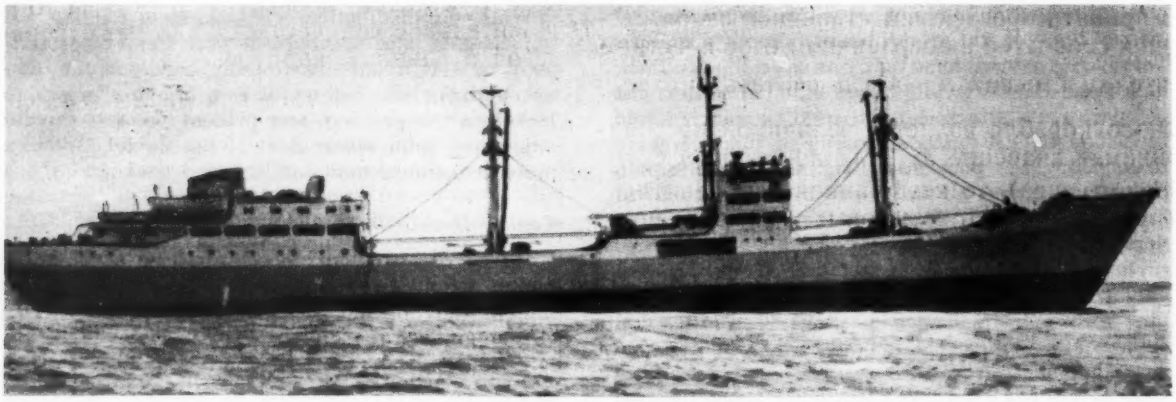
The Kherson area was responsible, in 1957, for the delivery of seven tankers, including *Zhitomir,* as well as several coasters, tugs and reinforced concrete floating docks.

On 1 January 1958 the I. I. Nosenko Shipyard in Nikolayev transferred its latest product, yet another *Kazbek*-class, named *Fridrikh Engels,* to the Black Sea Steamship Company. The vessel was placed under the command of Captain Votyakov, a graduate of the Odessa Higher Nautical School, who was taking his first independent assignment.

In late February mention was made of yet another tanker, *Nikolayevskiy Pioner,* being readied for service in the I. I. Nosenko Shipyard. When this vessel is delivered the *Kazbek*-class program will have reached approximately 44 units in service.

In ordinary practice, Black Sea Steamship Company tankers are taken out of service twice yearly and sent into shipyards for engine cleaning. Each period for the work is about two weeks and is reported to cost 300,000 to 400,000 rubles for labor and repairs. Ochakov engineers have suggested this service be reduced to an annual affair, explaining that the saving in time could result in an additional 65,000 rubles in profits, provided the work could be done by ship's force without taking the vessel out of service.

In May 1957 it was reported that a Soviet "super" tanker was in the preliminary stage of development. Plans appear to have gone forward with the news, in December, that at least one such tanker, capable of carrying 27,000 metric tons of cargo, was laid down in the S. Ordzhonikidzye Shipyard in Leningrad. As announced, the vessel will be 202.8-meters



Refrigerator diesel-electric *Aktyubinsk*

long, 25.8-meters in beam and will draw about 10.5-meters when fully loaded. Propulsion will be provided by a geared-turbine unit rated at 19,000-hp. Three 600-kw turbo-generators will provide necessary power and lighting. Two water tube boilers with a steam productivity of 34 tons per hour each will be installed to provide main and auxiliary steam, which will also motivate deck machinery and feed pumps. Cargo pumps will be of the centrifugal type, steam turbine driven, and each will be capable of handling 750 cubic meters of cargo per hour. A special hydraulic washing machine will be installed to clean tanks, and foam fire fighting equipment will be standard. A launching date of October, 1958, has been announced.

Early in December the Neva Ship Repair-Shipbuilding Yard, in the Leningrad area, reported the completion of the first 600-ton capacity river tanker designed by the Central Technical-Design Bureau of the Ministry for the River Fleet. Main propulsion is provided by two 300-hp engines, remote controlled from the bridge. An unusual feature in the design is the fact that liquid cargo will not be carried in ordinary tanks, but in five cylindrical tanks, each holding 120-tons, installed in the holds. This, it is claimed, will make it possible for the tanker to carry various types of liquids simultaneously. The cargo pumps will be able to unload the vessel in from four to five hours. Basically a shallow-draft vessel, the tanker was designed to carry fuel from refineries and storage points to farms and machine tractor stations on the various principal rivers. The first tanker was assigned to the Northern Dvina River.

Defects in Finnish-Built Cargo Carriers.

The Creighton-Vulcan firm, Turku, Finland, has built for the Soviet Union a series of what are called "timber carriers," which were assigned to the steamship companies in the Far East. Reported to be 85.05-meters long, 13.03-meters in beam, with height of side 6.5-meters, these cargo vessels are believed to be the 3100-ton capacity carriers mentioned for delivery, as additions to the original contracts, during the years 1956 through 1960 under the terms of the most recent trade agreement between the two nations. It is now reported that some of the vessels in the series have developed cracks in the sheer strakes forward and aft of the midships superstructure. A combination of low air temperature and severe working during Arctic storms caused the damage reported to *Stalino, Brest, Voroshilovsk, Elton* and *Uglich.* One vessel of the class, not identified by name, was lost in a storm. The cause of the loss is believed to be the direct result of hull damage and, from the report, it is suggested that the vessel went down with all hands. The building yard is taking steps to strengthen the weak area in existing vessels and will make design changes in ships under construction, of which three per year during the period of the agreement are to be delivered.

Whaler Base Under Construction

The long discussed whaler appears now to have been laid down in the I. I. Nosenko Shipyard in Nikolayev. The vessel will measure 218-meters in length and will displace, as originally announced, in the vicinity of 44,000 tons.

"THE SHIPBUILDER & M. E. BUILDER"

TECHNICAL PROGRESS IN SHIPBUILDING DURING 1957

This staff article was published in the January 1958 edition of "The Shipbuilder and Marine Engine-Builder."

THROUGHOUT THE YEAR, a great deal has been achieved in the technical field in so far as shipbuilding is concerned, as can be gathered by a perusal of the papers published by the various technical societies in this and other countries. We shall find occasion to deal in some detail with the content of these papers in later sections of this article, but, as has now been our practice for some years, we shall first of all make a few general remarks on the shipbuilding situation and some of the problems in the industry.

So far as can be judged, there appears to be very little, if any, reduction in the shipbuilding activities of the various maritime countries throughout the world. As in former years, the oil-tank ship represents a very substantial item in building programs and may, once again, be considered to be the backbone of the shipbuilding industry. Other types of ships of considerable interest are, however, included in the building program, and mention may be made of the large, fast, passenger vessels which are at present being contemplated, for service to the Antipodes. These represent quite important departures from the usual type of vessel in this trade, and the completion and service results of such ships will be awaited with great interest.

Research work continues to be an important feature of the technical development throughout the world, and it can be said, with certainty, that all the important maritime countries are giving attention to the improvement in building methods and the construction of more efficient ships. On an international scale, mention might be made of the Eighth International Towing Tank Conference, held in Madrid in September, 1957. The subjects discussed at this important meeting of naval architects were scale effect in propellers and self-propulsion factors, skin friction and turbulence stimulation, cavitation tests on propellers, sea-going qualities of ships, and forces and moments in a seaway.

So far as Great Britain is concerned, the activities of the Ship Division of the National Physical Laboratory and the work of the British Shipbuilding Research Association give some idea of the research work being undertaken. With regard to the former organization, the work has been almost equally divided between resistance and propulsion tests on ship models for specified designs for shipowners and builders on the one hand, and pure research work on the other hand. Naturally, close co-operation has existed between the Ship Division and the B.S.R.A. in this research work. Some of the subjects in the Division's own program of research work are scale effect in model resistance, the effects of roughness on resistance and the velocity distribution in the boundary layer, the effects of tank boundaries on resistance, propeller design methods, cavitation on propellers and hydrofoils, the resistance of trawlers and coasters, the behavior of light ships in bad weather and the sea-going qualities of ships. It is welcome news that the construction of the new laboratory at Feltham is somewhat ahead of schedule, and when this is completed, the research and commercial testing facilities will be greatly extended. Both the tank and the cavitation tunnel are scheduled to be completed in 1959.

The work of the British Shipbuilding Research Association, in addition to comprising some of the work already mentioned as being carried out at the Ship Division, also included many other aspects of naval architecture. For example, a very extensive and important research on the influence of deckhouses and superstructures on the strength of ships is being carried out, and much useful information has already been published. This has included work on box girders at the Imperial College, linked with

theoretical investigations. Further reference to this work is given in a later section of this article. In addition to this side of the work, the behavior of full-scale deckhouses is also being investigated when opportunity permits. Other B.S.R.A. projects include funnel-smoke investigations and the reduction of noise in marine installations, while the Association still continue to devote their attention to ship performance. The staff have attended many ship trials throughout the year and have also collected service data.

A great deal of ship research continued in the United States of America and, as is well known, programs of research have been sponsored by the American Society of Naval Architects and Marine Engineers. It is of interest, therefore, to note that, during the past year, the Society have commenced to publish a Journal of Ship Research, with a view to disseminating the results of research to all those interested. The first issue of this journal appeared in April, 1957, and was largely devoted to hydrodynamics studies, although, as was pointed out in the foreword to this issue, it is expected to cover all branches of naval architecture.

In Great Britain, a good deal of attention has been focused during the year on the subject of the education and training of naval architects and marine engineers, and, to this end, a symposium on education was held at a joint meting of the Institution of Naval Architects and the Institute of Marine Engineers. The writers of the papers in this symposium were Professor E. V. Telfer, Professor A. M. Robb, Professor L. C. Burrill, Professor S. J. Palmer, Captain I. G. Aylen, R.N., and Mr. S. F. Dorey.* The symposium provided a very large and fruitful discussion on this subject, the importance of which cannot be overestimated at the present time. There is little doubt that the shipbuilding industry includes among its ranks fewer highly technically trained personnel than other industries. It is true that in the past, and probably it could be said at the present, Britain has maintained her supremacy in the shipbuilding field. It might, however, be open to question as to how long this can continue, with the immense strides which have been made in other branches of technology. While it did not seem from the discussion that a large increase in the number of departments of naval architecture would be desirable, it appeared that there was room for one more Chair of Naval Architecture in Britain. This would still leave the country well behind others in the matter of numbers of graduates being turned out; but, in making such comparison, sight must not be lost of the fact that part-time technical education has, in the past, turned out, and is still turning out, a very good product which is extremely useful to the shipbuilding industry. The symposium brought forth many shades of opinion and it is well worthy of study.

One aspect of research which is, strictly speaking, a marine engineering problem, but which, nevertheless, has a considerable impact on the design of ships, is the application of nuclear power to marine propulsion. This has been given some considerable attention during the year. First, mention should be made of the work of the British Joint Nuclear Marine Propulsion Panel. This Panel was set up by the four major Institutions interested in marine matters in this country, *viz.*, Institute of Marine Engineers, Institution of Naval Architects, Institution of Engineers and Shipbuilders in Scotland, and North-East Coast Institution of Engineers and Shipbuilders. The object of this Panel is to stimulate the presentation and discussion of information on the application of nuclear power to marine propulsion. The Panel has produced a journal during the year, which is intended to be published at six-monthly intervals. This journal, the first two issues of which are now on hand, contains papers read at meetings arranged by the Panel, together with the discussions on these papers. The first issue contains two articles, one on the nomenclature of nuclear physics and the second on different types of nuclear reactors. These are intended as an introduction to the subject. Also in this first issue is a paper by Mr. C. D. Boadley, titled "Some Safety Considerations of Nuclear-power Reactors," which was actually read at the North-East Coast Institution of Engineers and Shipbuilders in November, 1956. The second issue of the journal contains a number of papers of general interest to the naval architect and marine engineer who wishes to make himself familiar with this important subject.

An important paper* on nuclear power for ships was read by Mr. S. Livingston Smith and Mr. J. E. Richards, before the Institution of Engineers and Shipbuilders in Scotland, in June, 1957. The information in this paper is of great interest, since many naval architects must have wondered, first how the weight of such a plant would compare with the machinery plus fuel of a conventional plant, second, about the question of first cost and, third, about precautions which would have to be taken with shielding. A detailed study is given in the paper, in which a comparison is made between a conventional 47,000-ton deadweight tanker of 15¾ knots speed and 16,000 S.H.P., and a nuclear-powered vessel. The same deadweight was assumed for the nuclear-powered ship; and one of the results of the analysis was that the same yearly average deadweight could be carried by the two ships when the increase in machinery weight for a nuclear vessel was 1,700 tons. Whether this result could be achieved in practice is a matter which is open to question.

* Two papers presented at this symposium were reprinted in the February 1958 JOURNAL.

* Reprinted in the February 1958 JOURNAL.

Another comparison which has been worked out in this paper is the permissible reactor cost because of the reduction in direct transport cost due to the saving in fuel required for the conventional ship. This was worked out for different costs of nuclear fuel and different assumed increases in machinery weight. To quote just one example—"At a nuclear fuel cost of 0.2 pence per S.H.P.-hr. and an assumed increase in machinery weight of 1,500 tons, the permissible reactor cost is 1.29 million pounds." Again one would like to ask is it possible to produce a marine reactor for this sum? We may comment on one point which would require consideration in these vessels. There is likely to be a large increase in weight of machinery at the after end. This will necessitate careful consideration of ballasting arrangements and may also lead to higher bending moments on the structure, and, hence, increase in structural weight to obtain equivalent strength.

In America, a somewhat similar study has been made by Mr. Cecil B. Ellis, in a paper entitled "Fluid Fuel Reactors for Nuclear Merchant Ships." In this paper, economic consideration is given to a 38,000-ton deadweight tanker, and it is stated that, for a voyage from the Persian Gulf to the Delaware River, the overall cost per ton of cargo delivered is likely to be between 20 to 40 per cent higher than for an oil-fired ship. The type of reactor described as being the most suitable for marine purposes is an aqueous homogeneous reactor. It is claimed that the total weight of the plant plus fuel is 1,000 tons less than the weight of the power plant and fuel for an equivalent conventional ship.

Summing up, it would seem that, in the light of the information contained in the two papers to which brief reference has been made, the great future in nuclear propulsion for merchant ships lies in the fact that the normal fuel is saved; and that, while the actual machinery may be heavier, the total weight of machinery plus fuel is less. Clearly, then, the highly powered long-voyage ship is going to benefit because of the large quantity of fuel which has to be carried in the conventional ship. It would seem, then, that the large modern tanker offers considerable scope in this respect, although, of course, in the overall economic picture the higher first cost cannot be ignored.

In this brief discussion on nuclear power for ships, we might mention, finally, a paper entitled "Some Problems in the Applications of Nuclear Propulsion to Naval Vessels." This was presented to the American Society of Naval Architects and Marine Engineers in November last, and was by a group of authors. It deals, essentially, with the problems arising in fighting ships so as to reconcile the requirements of safety with reduction in weight and space occupied, while at the same time retaining the benefit of nuclear propulsion.

DESIGN OF SHIPS

Under the heading of design of ships, we may include a number of interesting papers read during the past year on the design of the normal type of ship, and also on the design of certain special craft, such as floating docks.

In the former category, we would mention first of all the paper by Mr. J. Lenaghan, entitled "Ocean Iron Ore-carriers—Design Considerations," which was presented to the Institution of Naval Architects last spring. It is of interest to note that, at the time the paper was written, some 57 ore-carriers were under construction or on order for United Kingdom account alone, and this represents about 6 per cent of the total output of British yards. The ore-carrier is, therefore, a ship of considerable importance to the shipbuilder and the information contained in the paper will be very welcome indeed. Mr. Lenaghan gives curves from which it is possible to obtain a first approximation to dimensions for a given deadweight-carrying capacity. He also gives typical dimensions for actual ships, and discusses such matters as the layout of the ore compartments, ballasting arrangements and the position of the navigating bridge. He also deals with self-trimming ore-carriers.

An American paper of interest, by Mr. L. A. Harlander and Mr. R. Tate, is "Conversion of 'Mariner' Cargo Ships to Combination Vessels for West Coast-Australia Service," presented to the spring meeting of the American Society of Naval Architects and Marine Engineers. In this paper the conversion by the Oceanic Steamship Company of the two ships *Mariposa* and *Monterey* in 1955-57 is dealt with. The decision to convert these ships was made after an intensive study of the problem, involving several proposals for new construction, and was the result of the company's desire to re-establish their pre-war American flag passenger service between the United States West Coast and Australia.

The features of the "Mariner"-type ships which were considered suitable for this purpose were, first of all, the availability of hulls and principal propulsion units. Then, again, the operating speed of these ships, *viz.*, 20 knots was suitable for passenger ships. Other desirable features were the watertight-subdivision characteristics and the amount of passenger space which could be attained. Against these had to be set such disadvantages as the certainty that large quantities of solid and liquid ballast would be required, since the ships were originally designed as cargo ships, and the high and wasteful cargo 'tween decks. Apparently, however, on looking back, the decision to convert these ships was more than justified. One of the main structural alterations which was made was the almost complete removal of the existing superstructure and the construction of a new superstructure of welded steel with riveted crack-arresters.

The dimensions of the finished ships are 528 ft. B.P. by 76 ft. breadth molded by 54 ft. 3 in. depth molded to upper deck. The subdivision draft is 29 ft. 4 in. and the displacement 20,720 tons. The lightweight of the vessels is just over 14,200 tons, and the ships accommodate 365 passengers and a crew of 273. It is of interest to note that each ship carries 2,700 tons of permanent ballast and that, with the manipulation of fuel and liquid ballast, it is possible to meet the minimum metacentric height necessary to fulfill the requirements of two-compartment flooding. One final feature of interest upon which we would comment is the hatch-cover arrangement. These hatch covers consist of one or more pontoon sections, which fold up accordion fashion and are operated hydraulically. All the weather-deck hatches are fitted with rubber gaskets.

The naval architect has often had the charge made against him that his product is functional and that he has little interest in the appearance of the ship. While the technical features of a ship design must never be subordinated to other considerations, it is not true to say that the ship designer is not interested in appearance, and there are many modern vessels of high efficiency which are also pleasing to look at. Nevertheless, ships at times could be improved in appearance, and we note with interest a paper on this subject by Mr. Laurence Dunn, read at the summer meeting of the Institution of Naval Architects at Bristol. Entitled "Merchant Ship Design—Some Aesthetic Considerations," the paper deals largely with the external profile of the ship. Such matters as the shape of shell "sweeps," the stem and stern profiles, the outline of superstructure, funnel shape, openings in superstructure sides, mast design, etc., are discussed.

Information which will be welcome to the tug designer is to be found in a paper on that subject read before the American Society of Naval Architects and Marine Engineers by Mr. Doros A. Argyriadis. All aspects of the design of this type of craft are dealt with in this paper. Hull design and the lines are considered, and the question of the stability of the tug is given very careful consideration. The lines of several modern tugs are included and the particulars of many others are listed. The author considers the merits of several different types of propelling unit, and propeller design for the very special conditions obtaining in this class of vessel is dealt with in some detail. Finally, maneuverability and endurance are given consideration. As is common in many present-day papers, there is a useful bibliography at the end of the paper.

We make reference to two papers, dealing with the design of naval vessels. The first of these, "Design of Wooden Naval Vessels," was given by Mr. K. G. Evans, R.C.N.C., at the meeting of the Institution of Naval Architects at Bristol. This paper describes the modern approach to the construction of vessels in one of the oldest shipbuilding materials. The ships considered are over 100 ft. in length and a description is given of the structural details of an inshore survey craft 106 ft. in length. Wooden construction differs from that before the Second World War in these post-war vessels, in that extensive use is made of laminated timber for keels, stems and frames. In the paper will be found a description of the construction of laminated frames, as well as designs for composite plywood mahogany structures. The methods of theoretical stress analysis described in the paper suggest the greater use of ring connectors in shipbuilding. There is also a discussion on the preservation of timber and its protection against dry rot and marine borers.

The other paper to which reference has been made is entitled "Considerations Affecting the Design Endurances of Naval Ships," and was presented to the American Society of Naval Architects and Marine Engineers by Mr. Maurice R. Hauschildt. The author of this paper discusses the factors which affect trial and service endurances of oil-fired steam-driven combatant ships of the U.S. Navy. It is claimed that a 10 per cent saving in steam combatant fuel costs could be realized with better design and operating practice. As the current annual fuel bill of the U.S. Navy is 100,000,000 dollars, that would represent a considerable saving. It appears that design trial endurance fuel rates should be multiplied by a factor of 1.22 to adjust to the average service conditions fuel rate. The major factors which reduce service endurances are hull-surface condition, boiler operation and condition, weather, and turbine and gear operation. Among the items which seem to promise improved endurance performance in the future are a service-type excess-air indicator, better boiler-water analysis procedure and equipment, automatic boiler controls, permanent torsionmeter installations, improved hull joints, better utilization of weather data, and improvement in general design and arrangement to provide for ease of operation.

The standardization of large tankers has been dealt with by Mr. N. Carter in a paper of that title presented to the North-East Coast Institution of Engineers and Shipbuilders. The author of this paper has seen the development of the tanker from its modest dimensions in the 1920's to the huge vessels which are being produced to-day, and is well fitted to discuss this subject. He has given a brief account of the methods adopted at the present time to produce standardization so far as possible, and he has included proposals for a degree of standardization on a tanker of about 65,000 tons deadweight. He has also given some suggestions on hull form, hull structure accommodations and mooring arrangements.

In concluding this section on the design of ships, we would direct attention to some useful information which has been published in three papers in

the United States, and presented to the American Society of Naval Architects and Marine Engineers. Two of these refer to floating docks and the third to mobile off-shore platforms.

The first floating-dock paper deals, in a general way, with the problem of this special type of structure and gives some account of its operational duties, with some historical notes on the subject. The second paper includes a very detailed analysis of the design of the dock. In the development of the design, use is made of the conventional approach; but, in addition, detailed discussion is given of the most advanced concepts of design. The detailed development of the dock framing is dealt with, not only for steel-framed docks but also for those constructed of concrete and timber. Design charts and coefficients are given. While it is true that most naval architects are not confronted with this special problem, yet this paper is a welcome one on a subject which is seldom dealt with in shipbuilding circles.

The third paper—that on mobile platforms—concerns the operation of these structures in drilling operations in the Gulf of Mexico. While such matters as stability are not dealt with in the paper, the influence of wind forces and wave forces on the design are considered in detail. The consistency of the under-water soil, which forms a foundation for these platforms, is also discussed.

STRUCTURAL STRENGTH AND WELDING

The work on these subjects carried out during the year has covered a wide field, and we shall endeavor to present an idea of these researches by referring briefly to the highlights in the literature which has been published during the past year.

We would refer, first of all, to the twenty-fifth Andrew Laing Lecture by the Director of Naval Construction, Sir Victor G. Shepheard, R.C.N.C. Sir Victor chose for his subject "Structural Steels for Warship Building, with some Notes on Brittle Fracture." The two main problems dealt with in this lecture were hull structural design and special steels. The special problems in the hull strength of surface warships and submarines, particularly those giving rise to dynamic loading of structures due to underwater explosions, led to the inauguration of the Naval Construction Research Establishment and the provision of special facilities, some of which are unique.

Theoretical and experimental research has been carried out, with a view to ascertaining how various design features of warship hulls resist the dynamic and static forces imposed upon them, and special emphasis has been given to the postwar research on steel materials, welding and brittle fracture. These researches have been undertaken with the object of avoiding brittle fracture in normal structural steels and of developing high-yield steels for special application in warship construction. This research work has been directed not only to obtaining warships which will resist the forces of nature and forces due to enemy attack, but also with the aim of doing this with the absolute minimum weight, in order that the largest military loads can be carried.

As an example of the practical research facilities which are available at the N.C.R.E., it might be noted that in the design of the steam catapult for aircraft-carriers, a half-scale model of the structure was constructed and tested in the large testing machine to which reference has been made in the corresponding article in previous years. The model weighed 35 tons and is was possible to measure strain at some 300 positions, involving the use of some 2,000 strain gauges. The final design based on this experimental work resulted in a saving in weight of 45 tons for each catapult, *i.e.*, a saving of 90 tons per ship at flight-deck level.

In the field of materials, extensive research has been carried out on the notch sensitivity of existing steels, and from this investigation, two new specifications were drawn up for steels, to be known as "A"-quality and "B"-quality. "A"-quality is a notch-tough mild steel and applied to thicknesses of ½ in. and over. The specified yield-point is 16 tons per sq. in. up to 1 in. thick and 15 tons per sq. in. between 1 in. and 2 in. thickness. "B"-quality was intended to supersede both "S"-quality and "D.W." —quality, and, ultimately, the yield stress was fixed at 20 tons per sq. in. for thin plates and 18 tons per sq. in. for thick plates. Experimental work carried out on steel to these specifications has yielded very useful information, and has gone a long way to producing notch-tough steels of high strength.

In the past, there has been a great deal of work in connection with the problem of the flat plate. This, obviously, has an important bearing on the strength of ships, since a ship's structure consists largely of plate stiffened in either one or two directions. Additional work on this subject has recently been carried out by the British Shipbuilding Research Association, and the results have been embodied in a paper by Mr. A. G. Young to the Institution of Naval Architects. This latest work consists largely of experiments on plates with both lateral and end loads, and the results were compared with the theoretical solutions obtained by Timoshenko, Bleich, and Chang and Conway. The normal load was applied to the plates by means of air, a rubber bag being fitted on top of the plates. Both rectangular and square plates were tested, and strain and deflection measurements were made. The comparison between the experimental results and the existing theories showed that the approximate solution by Bleich was sufficiently accurate for all practical purposes. A set of design curves was developed from the results, and this should prove to be useful to the structural designer. The part of the ship in which the results of this work should, of course, be most useful is the bottom plating. This plating

is subjected to considerable forces due to water pressure, and, at the same time, has imposed upon it longitudinal bending stresses which, in the sagging condition, are tensile, but which, in the hogging condition, are compressive. As bottom plating is known to have been very troublesome in recent years, this research should assist in throwing light on a difficult problem.

Other work in the flat-plate field to which we would make reference is to be found in a paper, to the North-East Coast Institution of Engineers and Shipbuilders, by Mr. J. Clarkson. The scope of the work can be gathered from the title of the paper, *viz.*, "The Strength of Approximately Flat, Long Rectangular Plates under Lateral Pressure." This research, which was carried out at the Naval Construction Research Establishment, differs from the previous one referred to, in that only lateral loads are considered, and, also, while in the former membrane effects were considered unimportant, these are taken into account in the N.C.R.E. research. It is assumed that the plates have a small initial deflection and this leads to a non-linear solution of the problem. Local yielding at the edges of the plate is taken into account. The numerical examples indicate that the strength of the plate is greatly increased when there is a small initial deflection. Design data are presented in the form of curves, as with the previous work.

Another paper by the same author (Mr. J. Clarkson) deals with the grillage problem, and this, too, was given to the North-East Coast Institution of Engineers and Shipbuilders. There has been a great deal written about the grillage problem and many solutions put forward. The important point from a structural designers' point of view is how to make most efficient use of stiffening in two directions at right-angles. This is the object of the present research, the aim being to achieve minimum weight for the resulting structure. The work is limited to the simply-supported flat grillage subjected to a single concentrated load. A procedure has been developed by the author for designing this type of grillage, and for estimating the maximum stresses likely to be achieved. The design calculations show that the weight of plating is more than two-thirds of the total, and the author remarks that uncertainty still exists as to the thickness of plate required to withstand fairly concentrated loads without serious dishing. It is shown that savings in weight may be achieved by adopting rider plates attached to the beams to approach more nearly the equal stress condition, or by using more closely-spaced beams.

The problem of the sudden fracture of a large structure, which has manifested itself in ships on more than one occasion, still continues to occupy attention. One of the latest contributions to the subject is to be found in a paper by Mr. G. M. Boyd, entitled "The Conditions for Unstable Rupturing of a Wide Plate," read before the Institution of Naval Architects at their 1956 spring meetings. The approach to the problem used by Mr. Boyd is what has become known as "fracture mechanics," in which the conditions for the initiation and propagation of a crack are examined from the point of view of the mechanical concept of force, energy, velocity, etc. After giving some definitions and examining the mechanics of initiation of the fracture, various features, such as temperature, end effects, available energy and size effect, are examined.

Considering the application of the ideas expressed in Mr. Boyd's paper to ship fractures, the following may be noted:—(1) in many cases, the nominal stress has been fairly low; (2) there is a tendency for fractures to be more frequent and extensive at the lower end of the range of service temperatures; (3) the initiation of a great many of the service fractures has been associated with notches, due to either discontinuities in the design, faults in welds or accidental notches; (4) although, in some cases of fracture, there was no obvious impact, it can be said that, in the vast majority of cases, there was probably some such effect; (5) residual stresses which reach the yield point are inseparable from welded and even from riveted construction; (6) it is highly probable that fatigue operates in ships to produce and extend small cracks at points of stress concentration; and (7) it is well-established that, in the vicinity of welds, the parent metal is embrittled, *i.e.*, its transition temperature is raised by hardening, strain aging and quench aging.

Mr. Boyd's paper adds to the knowledge of this difficult subject and should help in bringing it to an ultimate solution.

The standard strength calculation, which appears to have found considerable application in recent years, is usually taken very much for granted and while such refinements as the Smith correction and the effects due to dynamic loading are well known, it is of interest to hear of others that may have an effect on the resultant stresses. Such refinements have been examined by Commodore H. A. Schade, U.S.N. (Rtd.), and his results included in a paper to the American Society of Naval Architects and Marine Engineers in November last. The effect of transverse bulkheads on the distribution of longitudinal stress is usually ignored, and this is one of the refinements dealt with in this paper. The effect is due to the fact that a considerable portion of the vertical loads caused by weight and hydrostatic pressure is transmitted to the ship's sides by the bulkheads as concentrated loads. A simple formula developed by Commodore Schade enables the effects of these to be taken into account without cumbersome calculation. The small effect due to transverse framing and the effect of torsional moments are also dealt with. One most interesting idea put forward in this paper is that of the maximum bending moment which could ever be obtained. To obtain this, the author imagines, instead of the

conventional sine or trochoidal wave, a wave with a vertical wave front, which, of course, is equivalent to a rectangular wave. He shows that, for a "Mariner"-type of ship, the bending moment obtained would be about 60 per cent greater than that from the conventional calculation.

The results of a series of experiments on the efficiency of welded aluminum-alloy brackets have been made known during the year. Mr. B. P. Opie gave a paper on this subject to the Institution of Naval Architects, the object being to discover how welded aluminum brackets would behave and the influence of the size of the brackets on the results. The specimens tested consisted of various aluminum-alloy sections welded to plating, with brackets of different sizes at the ends. The complete specimens were bolted in a special testing frame and loaded with three-point loading. It is not possible to comment on all the results obtained from these experiments, but it might be said that the type of bracket examined was capable of providing great rigidity at the ends of the stiffeners and the welding of the aluminum alloy was more than adequate for the purpose.

One result of particular interest was that, in certain of the tests, bracketless connections were used, which consisted of butting the beam against the vertical outstanding flange of the stiffener. These connections proved very satisfactory and although it is realized that, in welded construction, the question of accuracy of fit arises with this type of connection, yet it is evident that this is a type which should be given serious consideration, since the elimination of brackets must be a great convenience, especially in accommodations.

Mr. J. McCallum, in another paper to the Institution of Naval Architects, has also dealt with the subject of brackets. In this work, however, the author is concerned with the question of bending moments arising in beams which are necessarily of non-uniform section because of the large brackets they have at their ends. The rigidities of various types of end supports, such as deck beams, longitudinals, etc., were examined in detail, and a relationship between end fixation and relative rigidity was developed. An attempt was made to deduce an optimum size of bracket. An optimum bracket size exists because the bracket increases the moment of inertia of the beam at its ends, and as the end structural rigidity may remain constant, it is possible that the stress at the mid-span of the beam may increase beyond a certain size of bracket. The results of the theoretical work in this paper have been linked with the results obtained from the experiments in the testing machine at Glengarnock.

A further piece of research work sponsored by the British Shipbuilding Research Association has been made available in the form of a paper, to the Institution of Engineers and Shipbuilders in Scotland, by Mr. K. V. Taylor and Mr. M. N. Parker. This investigation concerned the strength of scalloped stiffeners and consisted of a series of experiments carried out at Glengarnock. The specimens tested were two types of stiffeners, *viz.*, 12 in. by 4 in. by 0.50 in. flange plates and 9 in. by 3 in. by 0.32 in./0.44 inverted angles. The specimens were of the usual Glengarnock three-stiffener type, formed by welding the stiffeners at 24 in. spacing to a sheet of plating 16 ft. long by 72 in. wide. The main result of these tests can be stated briefly. The cutting of scallops has no measurable effect on the maximum stress in a stiffener loaded in the elastic range, but deflection is increased for a given load. The scallops, however, decrease the stability of a section, and a scalloped specimen withstood only 75 per cent of the load required to cause failure in a similar specimen with intact web.

The question of plastic design has been dealt with in a paper by Dr. D. C. Drucker, to the American Society of Naval Architects and Marine Engineers. This method of approach to structural problems, which has, in this country, been greatly advocated by Professor J. F. Baker, of Cambridge, has, so far as we are aware, found little application in shipbuilding. Briefly, the method consists in determining the load which will cause complete failure of the structure and which carries its members into the complete plastic range. A factor of safety on this failing load is then used to find the working load which can be permitted in practice. In the present paper, the principles of plastic design are considered in some detail. It is claimed that there is a future for this method of design in ship construction.

A most important contribution to the strength of ships was made during the year by the publication of three papers read at the spring meetings of the Institution of Naval Architects. These papers were all concerned with the superstructure problem, the authors being Mr. J. C. Chapman, Mr. A. J. Johnson, and Mr. J. B. Caldwell. This problem has been fairly extensively examined in recent years, both in this country and in America. The question of steel, as well as aluminum, superstructures has been considered. The problem is important in that one wishes to know, first, to what extent the superstructure can be considered to take part in the longitudinal strength of the ship, and, second, in the vibration problem, the contribution a superstructure makes to the stiffness of the hull girder must be assessed.

Two points emerge from recent researches, *viz.*:— (1) due to the discontinuity at the end of the superstructure, the stress in the superstructure will not build up to the full theory of bending stress until some distance from the end; and (2) because of the elasticity of the deck upon which deckhouses stand, the curvature of the deckhouse or superstructure will not be the same as that of the main hull, and, therefore, the stress will be reduced due to this cause.

It is not intended to discuss here any of the details of the three papers referred to, as this would be a very lengthy task. It is sufficient to say that theories have been advanced to explain the superstructure behavior, and that, in some cases, the results have been checked by experiments on models. The approach by the three authors is different, and all use more or less approximate solutions to the problem. It can, however, be stated that this work, in conjunction with other work of a similar nature published in recent years, will now enable the effectiveness of at least a one-tier superstructure to be determined with a fair degree of accuracy. There are, of course, many problems still to be solved, such as the two or three-tier superstructure, common in large passenger ships, and the influence of window and door openings, as well as such features as the break in the line of the side of the house, on the stress distribution. The publication of further work on this important aspect of strength of ships will be awaited with great interest.

An interesting account of the ever-present notch-toughness problem is to be found in the *British Welding Journal* for February, 1957. This is by Mr. N. Christensen and Mr. B. Angland, and gives an account of tests on 14 ship-plate steels and one molybdenum-alloy steel. These steels were tested by means of various Charpy impact test methods, by impact testing of bars in full plate thickness, and by static tensile, bend and slow bend tests. A better approach to the conditions of service failure without preceding deformation has been attempted in the static tests, by introducing a narrow embrittlement zone beneath a sharp indentation. The arrest of brittle cracks originating from such notches has been evaluated as a criterion of fracture propagation transition. A trend has been observed in the derivations of fracture arrest temperatures from transition temperatures based on Charpy impact data, indicating that highly ductile, fully killed steels may not be able to arrest brittle fractures in proportion to their ability to resist fracture initiation.

Finally, we would mention a paper by Mr. W. Muckle in the *British Welding Journal* for April, 1957. This paper is on welded aluminum deckhouses, and is mainly concerned with the possibilities of constructing these of plate only. This elimiates the conventional plating and stiffener arrangement, and it is shown that considerable weight can be saved by the adoption of this method of construction. The author has also dealt with the conventional type of construction, involving either transverse or longitudinal framing, and at the end of the paper, he makes a suggestion concerning the possibility of a deckhouse or superstructure completely dissociated from the hull as a means of reducing the stress and avoiding the bi-metallic joint.

RESISTANCE AND PROPULSION

Research activity and the collection of useful data in the realm of resistance and propulsion have led to the publication of several papers, to which we shall refer in turn.

First of all, we would discuss the question of frictional resistance. A further contribution to this subject has been made by Mr. G. Hughes, who has done much in this field in the past. His latest work is to be found in a paper which he read to the Institution of Naval Architects at their meeting at Bristol. This bears the title "The Prediction of Smooth Ship Resistance from Model Data," and in it Dr. Hughes gives a review of the work which has been done by the Ship Division of the National Physical Laboratory in recent years. It appears that there is a close resemblance between the scale-effect laws for plane surfaces and for a variety of types of hull form over a wide range of Reynolds and Froude numbers. In general, the rate of scale effect is a little greater for ship models than for plane surfaces at corresponding values of the viscous resistance coefficient. Three proposals are made in Dr. Hughes' paper for model to ship viscous formulations, which are as follows: — (*a*) to use the plane-friction formulation $\frac{r \times 0.066}{(\log R_n - 2.03)^2}$ applied to the low Froude number position, (*b*) to use the formulation $\frac{0.080}{(\log R_n - 2)^2}$ (This is a single-line formulation and is designed to meet the wishes of those who consider it premature to use a formulation with a varying form effect), and (*c*) to use the formulation $\frac{0.070}{(\log R_n - 2.25)^2}$. This last is an alternative single-line formulation designed to allow for the indication that the slope should be relatively steeper at low Reynolds number than given by the plane-friction formula. It is stated that either (*b*) or (*c*) could be converted into a formula with varying form effect by the use of a simple multiplying factor. It is the author's opinion that proposal (*a*) is to be preferred to either (*b*) or (*c*).

The accurate determination of the normal pressure on the hull of a ship or a model enables a direct measure of what may be called the residuary resistance to be made. Such a direct measure is invaluable in deciding what is the frictional resistance of, say, a model. To this end, Mr. H. Hogben has carried out a series of experiments on models in the Department of Naval Architecture at King's College (Durham University), Newcastle-on-Tyne, and has given the results in a paper to the Institution of Naval Architects. The model chosen was a Lindblad form and was 100 in. in length. Pressures were measured by means of an open-topped water manometer at 76 positions and at nine speeds in the range $V/\sqrt{L} = 0.8$ to 1.1. Wave-profile measurements made photographically were used to assist in extrapolating the pressure measurements up to the free surface. The results of the experiments were compared with the calculated wave

resistance for the form. As the author observes, the agreement between the calculated and measured resistance is not close. Nevertheless, there is little doubt that this discrepancy will eventually be explained, and that the method of procedure outlined in this paper will ultimately prove to be very useful to the research worker.

Further data on a now well-known series of models—the American Series 60—have been given during the year in a paper to the American Society of Naval Architects and Marine Engineers by Dr. F. H. Todd, Mr. G. R. Stuntz and Dr. P. C. Pien. This is the fourth paper dealing with this series. The earlier papers described the way in which the parent lines were chosen, the resistance and propulsion experiments carried out on the five original parent models ranging in block coefficient from 0.60 to 0.80, and tests on a number of models were made to explore changes in the longitudinal position of the center of buoyancy. For any given block coefficient, these tests covered only one value of length-beam ratio and one value of beam-draft ratio. The five Series 60 models, having the near optimum position of the center of buoyancy and covering the full range of block coefficient, were, therefore, taken and the lines varied geometrically to cover L/B values from 5.5 to 8.5 and breadth-draft ratios from 2.5 to 3.5. In all, this new series consisted of 45 models, all of which were tested for resistance and propulsion. The present paper sets out these results. This research has resulted in a paper of more than 100 pages in length, and it is obviously impossible to discuss the results in detail. It is sufficient to say that this paper, together with its three predecessors, will form an invaluable collection of data for the designer, and should provide him with an excellent means for assessing the merits of various types of form.

Further information has been provided, in this country, on hull form in a paper, or, rather, two papers, read to the Institution of Naval Architects by Mr. R. E. Blackwell, Mr. G. J. Goodrich, and Mr. D. J. Doust. This is the British Shipbuilding Research Association's program on forms of 0.70 block coefficient, and, in the present papers, the influences on the resistance of variations in the longitudinal position of the center of buoyancy, the breadth-draft ratio and the length-displacement ratio have been investigated.

Five models were tested, giving L.C.B.'s from 1 per cent of the length aft of amidships to 2 per cent of the length forward of amidships. Complementary self-propulsion tests were carried out, three different propellers having been used for each model. The results showed that, up to a speed-length ratio of 0.70, the position of L.C.B. was not critical, but above this speed, L.C.B. amidships appeared to be the optimum for the series. The effect of the position of the center of buoyancy on the components of propulsive efficiency was small.

The second series of experiments divided itself into two groups; one giving a range of breadth-draft ratio with constant displacement-length ratio, and the other giving a range of displacement-length ratio with constant breadth-draft ratio. One model was common to both sets. The parent form for this second series of tests was one having a position of the center of buoyancy 0.02 per cent L aft of amidships, with a 6-ft. bilge radius. The results of the experiments show that increasing the breadth-draft ratio above 2.12, the value for the parent form has the effect of increasing the resistance coefficient over the whole working range of speed and at all drafts. Decrease in length-displacement ratio gives an increase in resistance coefficient at all drafts. The increase becomes greater as the length decreases from 400 ft. and as speed-length ratio increases, but is less marked as draft decreases. The results obtained from these latest experiments have been found to be in good agreement with those obtained by other investigators.

In the field of small craft, we would draw attention to the paper read by Mr. J. B. Griffith to the Institution of Naval Architects at Bristol. This deals with tug power in relation to the towage of swim-ended barges. The paper describes, among other things, model experiments carried out to examine the problem of towing different numbers of barges. It is interesting to note that in the conventional way of towing barges in pairs abreast, with the first pair brought well up to the tug, much of the tug's available power is expended in the reaction of the propeller race on the leading rank of the barges. If the tow could be dropped far enough astern, considerable savings in power could be achieved. Another factor of importance is the interference effect of two barges towed abreast. This, apparently, is very great; and in experiments carried out with the two front barges held apart about 9 in., a great increase in speed was achieved for the same power. It is considered that if these problems of interference between barges, and between barges and tug, could be solved, a great saving in capital cost could be achieved on a tug to do the same work.

Further work of the British Shipbuilding Research Association is embodied in a paper on the analysis of voyage data, by Mr. R. E. Clements before the North-East Coast Institution of Engineers and Shipbuilders. This is a problem in which increasing interest has been shown over the past few years, and among the useful information which can be derived from such analyses are the allowances to be made on fine-weather trial results to obtain service powers and the influence of fouling on the resistance. The British Shipbuilding Research Association have derived a method of analyzing data which enables these two effects to be separated out. This is a multiple regression method. A suitable weather scale has also been derived, from which it is possible to estimate the perform-

ance of a vessel in unrestricted waters having only the wind strength and direction. Work of this type is invaluable, as it enables more accurate estimates to be made of the power required in service, which should lead to economies in propelling machinery.

We have to record a number of results of full-scale trials on ships, and the first we would mention are those on the *Lubumbashi*, which are included in a paper by Professor G. Aertssen to the Institution of Naval Architects and the Institute of Marine Engineers. The trial results on this ship have already been published, and those given in the present paper refer to trials carried out as the age of the vessel increased. Records were taken during two Atlantic voyages in varying weather conditions. Particular attention was paid during the first three years of the life of the ship to increasing frictional resistance. Information on the subject was obtained by means of speed, thrust and power measurements, as well as by Pitot traverses taken over the bottom forward, aft and amidships. Attempts have been made to correlate these data with roughness measurements.

Another series of trials and voyage data of interest are the trials on the gas-turbine ship *John Sergeant*. These have been given in a paper by Dr. J. J. McMullen to the American Society of Naval Architects and Marine Engineers. This ship is claimed to be the world's first gas-turbine vessel. It is one of the four "Liberty" ships converted under the Maritime Administration's "Liberty" Ship Conversion and Engine Improvement Program. The results obtained from this ship appear to have been entirely satisfactory, and the author of the paper predicts that, while the gas turbine will not oust all other means of propulsion, about 25 per cent of the dry-cargo ships, utilizing more than 7,000 S.H.P., ordered in the United States of America during the next five years will be propelled by gas turbines.

Turning now to matters concerning propellers, we would first of all refer to a paper given to the Institution of Naval Architects entitled "Propellers in the Wake of an Axisymmetric Body," by Mr. R. Hickling. This paper reconsiders the basic, generally-accepted assumptions upon which the theory and design of a propeller behind a ship or body is based. For example, the thrust-deduction concept is criticized, and it is believed that the propeller/body combination should be considered in its entirety. The intention of the paper is to develop an accurate design theory of wake-adapted propellers and of propeller-body combination in general. The kind of body dealt with is a body of revolution coaxial with the axis of the propeller. This arrangement should apply to under-water missiles and probably to submarines. The theory has been developed for a contra-rotating propeller, of which the case of a single-screw is a simplification. In the theory developed in this piece of research, several important aspects have not been considered, such as the drag of the propeller blades, the effect of the finite width and thickness of the blades, and the influence of radial velocities on the trailing vortex system. These problems could, however, be approached in the same manner and incorporated in a more general theory.

Propeller students will be interested in the work proceeding at the National Physical Laboratory in the Lithgow Propeller Tunnel, and we would refer them to the paper by Mr. A. Silverleaf and Mr. L. W. Berry on this subject, presented to the Institution of Engineers and Shipbuilders in Scotland. During the past three years, the tunnel has been extensively modified, and a great deal of new equipment and instruments introduced for the more effective study of propellers, of fixed bodies, and of the performance of the tunnel itself. Examples of the work which is being carried out include comparative propeller tests, researches on propellers in non-uniform flows, scale-effect studies, tests on rudders, and basic research on water-tunnel performance.

Mr. T. P. O'Brien has given the results of another piece of National Physical Laboratory research in a paper to the North-East Coast Institution of Engineers and Shipbuilders. This concerns the influence of blade thickness on model-screw performance. Calculations and experiments were carried out for two types of screws, one having N.P.L. sections and the other having segmental sections, and each having varying blade thicknesses. Some brief conclusions from this research may be made. Increased blade thickness is associated with reduced optimum diameter, and an increase of 100 per cent corresponds to a reduction in optimum diameter of 10 per cent. Increased blade thickness is associated with adverse free-running performance under cavitating conditions, but is not associated with adverse towing performance under cavitating conditions. The effects of increased blade thickness with segmental sections are more marked than with Troost *B* or N.P.L. sections.

The paddle-wheel research to which we have made reference in past years has been continued, and a further paper on the subject has been produced by Mr. H. Volpich and Mr. I. C. Bridge and presented to the Institution of Engineers and Shipbuilders in Scotland. This is mainly concerned with the correlation between the model results and the ship, and this has been achieved successfully. It is stated that the terms of reference of the original research into paddle wheels were to evolve a practical system whereby the paddle wheel could be designed, and it is gratifying to learn that it is believed that this has been achieved.

In a paper to the same Institution, Captain E. C. Goldsworthy and Mr. W. Betts Brown have given an account of the Voith-Schneider method of propulsion. It will be remembered that this means of propulsion is almost like a paddle wheel, with its

axis vertical. The present paper reviews the development of this type of propulsion, and describes the water tractor—an alternative to a tug—with some notes on minor modifications to driving mechanism and alternative propeller designs.

We would conclude this section by referring our readers to some information which has been given concerning the Convair Towing Tank. This is included in a paper by Mr. T. L. Thornburg to the American Society of Naval Architects and Marine Engineers. The paper deals with the problems which have arisen during the first year of operation of the high-speed towing tank at Convair, California.

MISCELLANEOUS TOPICS

In this final section, we shall refer briefly to various matters which have been discussed during the past year.

We would first direct attention to a paper by Mr. A. J. Johnson and Mr. P. W. Ayling on ship vibration, given to the North-East Coast Institution of Engineers and Shipbuilders. This concerns the graphical presentation of frequency data, and is part of a comprehensive program of research work on ship vibration being carried out by the British Shipbuilding Research Association. One of the main factors dealt with in this particular aspect of the investigation was the influence of deckhouses on the vibration frequency. The method of taking deckhouses into account was based on the work carried out by the Association on the effectiveness of deckhouses, and to which reference has already been made in an earlier section of this article. A series of calculations was carried out to cover a wide range of ships, from which it was possible to plot curves enabling a rapid estimate to be made of the influence of a deckhouse. We may comment here that the deckhouse allowance in vibration frequency calculations has always been of very doubtful accuracy, and the present work, therefore, helps to solve yet another problem in naval architecture.

Comment has been made, on earlier occasions, regarding the work which has been carried out by the Ship Division of the National Physical Laboratory on sideways launching of ships. Mr. D. J. Doust and Mr. E. MacDonald have continued this work and have published some further results in a paper to the Institution of Naval Architects. The earlier work on this subject was concerned mainly with trawler types and the range of stability confined to rather narrow limits. The more recent work has extended the range of stability to include coasters and dredge forms, *i.e.*, up to GM/beam = 0.4. Because, with the fuller forms, concern was felt over the possibility of inadequate clearance from the beds and banks of waterways, it was considered desirable to investigate the upper limit of static drop. This paper adds to the data available on what may be called an unusual problem in this country.

In the field of ship oscillations, attention might be directed to a further American paper by Messrs. B. V. Korvin-Kroukovosky and W. R. Jacobs on the subject of the pitching and heaving of ships in regular waves. The paper is another contribution to the gradual development of this important subject which has extended over a long period of years, and to which American authors have contributed a great deal in recent years.

In conclusion, reference is made to an account of the performance of the stabilizers in the *Mariposa* and *Monterey*. This can be found in a paper by Mr. John E. Flipse to the American Society of Naval Architects and Marine Engineers. Stabilizers are now quite common in this country, but not so common in America, and this paper gives the first service account of their performance in American ships. This is regarded as only an interim report and the results of long-service experience will be awaited with great interest. However, so far as can be judged, the stabilizers have behaved successfully and no doubt the future will see their greater use in the American merchant marine.

Certain requirements for the generation of power by thermonuclear processes have been recognized. A temperature of 100 to 350 million degrees Centigrade is required for a sustained fusion reaction. The material to be fused must be helium or hydrogen, or their isotopes. Deuterium, a hydrogen isotope, is the most promising. An extremely low density of the fuel appears necessary—that corresponding to a pressure of about one ten-thousandth of an atmosphere. At the temperatures achieved to date, about 5,000,000° C, the fusion fuel becomes a plasma of electrically charged nuclei and electrons. A magnetic field, caused by the passage of an extremely high current through the plasma, serves to "pinch" the plasma stream and keep it away from the walls of the container.

—from "Mechanical Engineering," March 1958

Gravity masurements at sea have been successfully accomplished for the first time. U.S.S. COMPASS ISLAND successfully took gravimeter data of a type heretofore possible only by using a submarine. Gravity measurements help determine the shape of the earth, the direction of its center and give information relative to its density. The data were obtained as a part of a program to investigate gravity measurements all over the world during the International Geophysical Year.

—from "Journal of the Franklin Institute," February 1958

An important step in the development of a gas-cooled nuclear reactor ship propulsion plant was recently taken in the award to General Dynamics Corporation by the Atomic Energy Commission and the Maritime Administration of a development contract. Expected to require from five to seven years for completion, the contract calls for development of a closed cycle gas turbine plant with the gas-cooled reactor. The General Atomic and Electric Boat Divisions of General Dynamics will participate.

—from "Nucleonics," February 1958

FRANK BONI

THE DESIGN OF A LIQUID METAL HEATED BAYONET TUBE STEAM GENERATOR

THE AUTHOR

graduated from the University of Michigan in 1947 with the degree, Bachelor of Science in Engineering (Mech. Eng.). For about three years he was associated with the Babcock and Wilcox Company as a design analyst in the Marine Engineering Department. Since 1950 he has specialized as a mechanical designer of engine heat transfer apparatus with the Griscom-Russell Company at Massillon, Ohio. Currently he is supervisor of the Special Projects Engineering group of that company.

INTRODUCTION

In recent years various configurations of heat exchangers for liquid metal to water and/or steam service have been designed, fabricated and tested. These heat exchangers are commonly designated steam generators. The steam generator under discussion includes an evaporator, superheater, and a steam drum. The latter may be a separate unit or combined in a single vessel with the evaporator. These remarks will be limited to the first two components. Operating experience has indicated structural deficiencies in some equipment of this nature. These have been attributed by Fleischmann and Koenig (1) * to faulty material, corrosion, overstressing, and inadequate structural detail. It is recognized that there may be other contributing factors.

It has been determined that structural fracture or damage occurs more frequently in the vicinity of the tube-tube sheet attachment than in any other region.

In an effort to overcome these weaknesses and to provide other improvements a study group was assembled and basic design objectives were established. The group was composed of manufacturers in the boiler and heat exchanger industry as well as a customer who had operational experience with liquid metal heated steam generators. The author's company proposed a bayonet type steam generator as embodying the features that would better accommodate the unique problems presented by the use of alkali metals as heating media in the generation and superheating of steam.

It is recognized that in such a steam generator the heat transfer, fluid flow, and structural design are closely interrelated. However, only the latter is considered in detail. The thermal and hydraulic design involved are covered in the literature. Liquid metal heat transfer coefficients and flow characteristics are given by the Liquid Metal Handbook (2). Boiling water heat transfer has been treated by many authors, for example, King and Andrews, (3).

An overall heat transfer coefficient, or "rate," of approximately 600 Btu/(hr) (sq.ft.) (deg.F) can be anticipated in an evaporator of the subject design while a "rate" of 200 is applicable in the orifice baffled superheater.

DISCUSSION OF PROBLEM

The Reactor Handbook (4) indicates that liquid metals have the best combination and range of physical properties for application as fast or intermediate type nuclear reactor coolants. It should be added that liquid metals also have application in high temperature thermal reactors. Miller and Cooper (5) cite the advantages and disadvantages of sodium as a reactor coolant. Most of the liquid metal work to date has been with the alkali metals, particularly sodium and sodium-potassium alloys (NaK).

Sodium is especially attractive as a heat transfer

* Numbers in parenthesis refer to the Bibliography at the end of the paper.

NOMENCLATURE

The following nomenclature is used in this paper:

A = cross-sectional area, sq. in.

D = flexural rigidity of cylinder or ring $\frac{Ey^3}{12(1-\nu^2)}$ lb-in^2.

E = Elastic Modulus, psi.

e = base of Napierian logarithms = 2.718.

h = heat transfer coefficient, $\frac{\text{Btu}}{(\text{Hr})\,(\text{sq. ft})\,(\text{deg. F})}$

k = thermal conductivity, $\frac{\text{Btu}}{(\text{Hr})\,(\text{ft})\,(\text{deg. F})}$

l = length of cylinder or ring, ft. or in., depending on application.

$m = \sqrt{\frac{h}{ky}}$, (ft).

n = number of tubes within individual tertiary fluid chamber ring.

p = hydrostatic pressure, psi.

P = gravitational type load, lb.

r = radius, in.

t = temperature, °F.

$\triangle T$ = temperature difference, °F.

$v = x\sqrt{\frac{h}{ky}}$, dimensionless.

$v_l = l\sqrt{\frac{h}{ky}}$, dimensionless.

x = distance along length of shell or ring, ft.

y = cylinder wall thickness, ft. or in., depending on application.

α = linear coefficient of expansion, in. per in. per deg. F.

$\beta = \left(\frac{3(1-\nu^2)}{r_m{}^2y^2}\right)^{3/4}$, (in)$^{-1}$.

δ = deformation or radial expansion, in.

ν = Poisson's ratio, dimensionless.

σ = stress, psi.

Subscripts:

a = ambient condition.

i = inside dimension.

$_l$ = condition at terminal end of ring or cylinder.

m = mean value.

o = outside dimension or condition at leading end of ring.

r = property of tertiary fluid chamber ring.

t = property of tubes within ring.

Z = longitudinal direction.

θ = tangential direction.

medium in that it possesses a relatively high thermal conductivity and reasonably good heat capacity. It has a conductivity, k, of 40 Btu/(hr) (ft^2) (deg. F per ft) and a heat capacity, c_p, of 0.305 Btu/(lb) (deg.F) at 800 degrees F as compared to values of 16 and 0.235, respectively, for NaK-56 (56% K by weight). For these and other properties see reference (6). However, the steam generator utilizing sodium as a heating agent requires preheating above 208 degrees F.

Large temperature differences prevail in a steam generator having a liquid metal heat source. The large temperature differences result from these factors:

(1) the relatively low heat capacity of liquid metals,
(2) high operating temperature range of liquid metals, and
(3) the low critical temperature of water, approximately 705 degrees F.

The first of these combined with a desire for minimum pumping power expenditure are responsible for the large liquid metal temperature drop normally encountered in steam generators. The temperature level in the second factor can be as high as metallurgical considerations will permit. While the large temperature differences may induce high thermal stresses this liability can be more than offset by a more efficient overall power plant. The significant advantage in the steam generator is the reduced heat transfer surface required to transmit the heat load.

Sodium or liquid metal and water interleakage may create problems. Some of the more significant occurring in a non-radioactive system are:

1. Hydrogen is liberated in the chemical reaction between the fluids resulting in a pressure rise in the liquid metal system which is normally designed for high temperature and low pressure.—King and Nelson present a detailed discussion of liquid sodium-water reactions in the Liquid Metals Handbook (7),
2. corrosion on the liquid metal side by sodium or potassium oxides on hot containing elements, and
3. corrosion and caustic embrittlement on the water side by hydroxide solution at temperature.

In addition to these the following are possible in a nuclear reacting system:

1. Hydrogen is a moderating element and thus may effect the reactor physics,
2. health hazard if radioactive fluid is entrained in fluid traveling out of shielded area,
3. water breakdown induced by emission of gamma rays from activated heating medium, and
4. oxygen corrosion on the water side can be alleviated by scavenging water treatment.

In consideration of these possibilities a double barrier to interleakage has been provided, see Figure 1. In view of the alternative of designing the liquid metal system to withstand the pressure rise a double leakage barrier may be justified on an economic basis even in a system accommodating an intermediate heat exchanger.

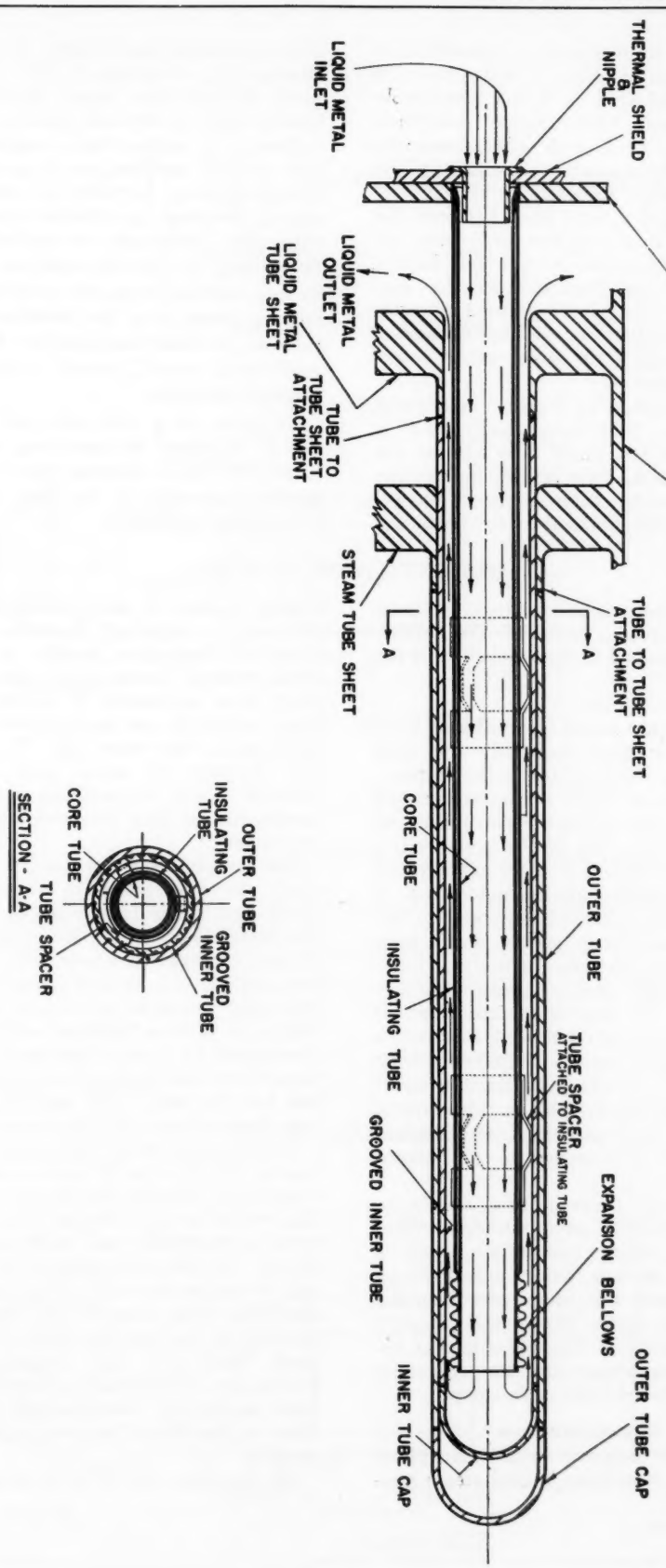


Figure 1. Enlarged Detail of Bayonet Tube. Note: Evaporator tube shown, superheater tube identical except for core tube which is not insulated.

Further, a tertiary fluid system is provided in order to detect and locate leakage by either fluid. A gaseous system was adopted as being compatible with the operating fluids. The principal drawback of such a monitoring fluid with a mechanically bonded duplex tube appears to be the relatively low gas thermal conductivity. This can be largely circumvented by furnishing a tight bond between the duplex tubes. Contact heat transfer coefficients are discussed by King and Andrews (3) for duplex tubes and by Brunot and Buckland (9) for machined joints. Barzelay, et al., (8) present information showing the variation of contact resistance with pressure. McAdams (10) gives other references on contact coefficients.

The duplex tube indicated by Figure 1 consists of two concentric tubes. The mechanical bond is achieved by expanding the inner tube against the outer tube. The monitoring fluid is contained in the spaced grooves between the tubes.

While it is generally preferable to have the higher pressure fluid inside the tubes of a heat exchanger it is desirable in the case of a gas monitored duplex tube steam generator to place the liquid metal on the tube side for several reasons:

First, in a mechanically bonded duplex tube the heat transfer performance is predicated on a metal-to-metal contact between the concentric tubes. This contact, or bond, in a duplex tube with comparable expansion coefficients is assured during operation by routing the heating medium through the tubes so that thermal expansion produces a further interference pressure at the interface. In some applications an idealized combination of thermal expansion coefficients would permit passing the hot fluid through the shell.

Secondly, as a rule minimum sodium inventory can be achieved by operating with sodium in the tubes. This is a common objective in liquid metal systems especially if the fluid is radioactive from a shielding standpoint.

RESOLUTION OF PROBLEM

In consideration of the unique situations outlined above a particular solution is required. The following procedure was employed in the resolution of the problems.

UTILIZATION

Boiling water and liquid metal films offer so little resistance to heat flow that essentially the total temperature difference between the bulk temperatures of the hot and cold fluids occurs within the element wall or walls separating the two fluids. As thermal stresses are a function of the temperature drop across an element, higher stresses are induced in elements separating these specific fluids than in those where the heating medium is gaseous, for example. It becomes especially important that a tube configuration offering a maximum of thermal flexibility with respect to the shell or other tube elements be considered so that additional thermal stresses are either minimized or eliminated entirely during operation. Application of the bayonet tube in a system utilizing a liquid metal heating agent affords these significant advantages: a tube bundle that is independent of shell constraint; and freedom of each individual tube with respect to the balance of the tube bundle.

The compartmentation concept (the ability to isolate a small tube group) is advantageous in most liquid metal heated steam generators. Such a scheme, see Figure 2, permits, among other things, the use of smaller, thinner tube sheets, for example, which reduce thermal stress levels and simplify fabrication and maintenance. The benefits that accompany such an arrangement and the associated disadvantages are discussed later in this paper.

MATERIALS OF CONSTRUCTION

Previously austenitic stainless steels were given primary consideration in sodium heated steam generators because of their resistance to sodium. It was desirable to construct the steam generators of one alloy for fabrication reasons as well as operating stress reasons. Consequently, both water and sodium sides were fabricated of stainless steel. However, these materials are susceptible to stress corrosion cracking on the water side (1), (11). Stress corrosion damage can occur upon brief exposure to chloride ions in the presence of oxygen. The oxygen mechanism in this phenomenon is not fully comprehended.

The carbon steels and low chromium content alloy steels are susceptible to oxygen attack. Oxygen generation at the tube walls is increased by radiation breakdown of the boiler water. The resultant oxygen corrosion is a relatively slow reaction. It is assumed that the oxygen concentration in the steam generator would be minimized by water treatment. Additives such as sulphites and hydrazine might be considered for water treatment. The use of an intermediate heat exchanger would alleviate the problem but the water still requires some treatment if high temperatures and pressures are to be used.

Conventional boiler materials, e.g., ASME Specification SA-212, can be used on the water side of the evaporator because the oxygen corrosion problem that would be encountered with the use of this material is reasonably well understood and can be controlled. The effect of radiation, however, on the control of oxygen corrosion is not well known. Further, there has been considerably more fabrication experience in the industry with carbon and low alloy steels than with the austenitic stainless steels. Twelve per cent chromium ferritic stainless steel has been considered and rejected on the ground that there is insufficient experience with it as a boiler material.

On the steam side of the superheater 2¼ CR-1 MO

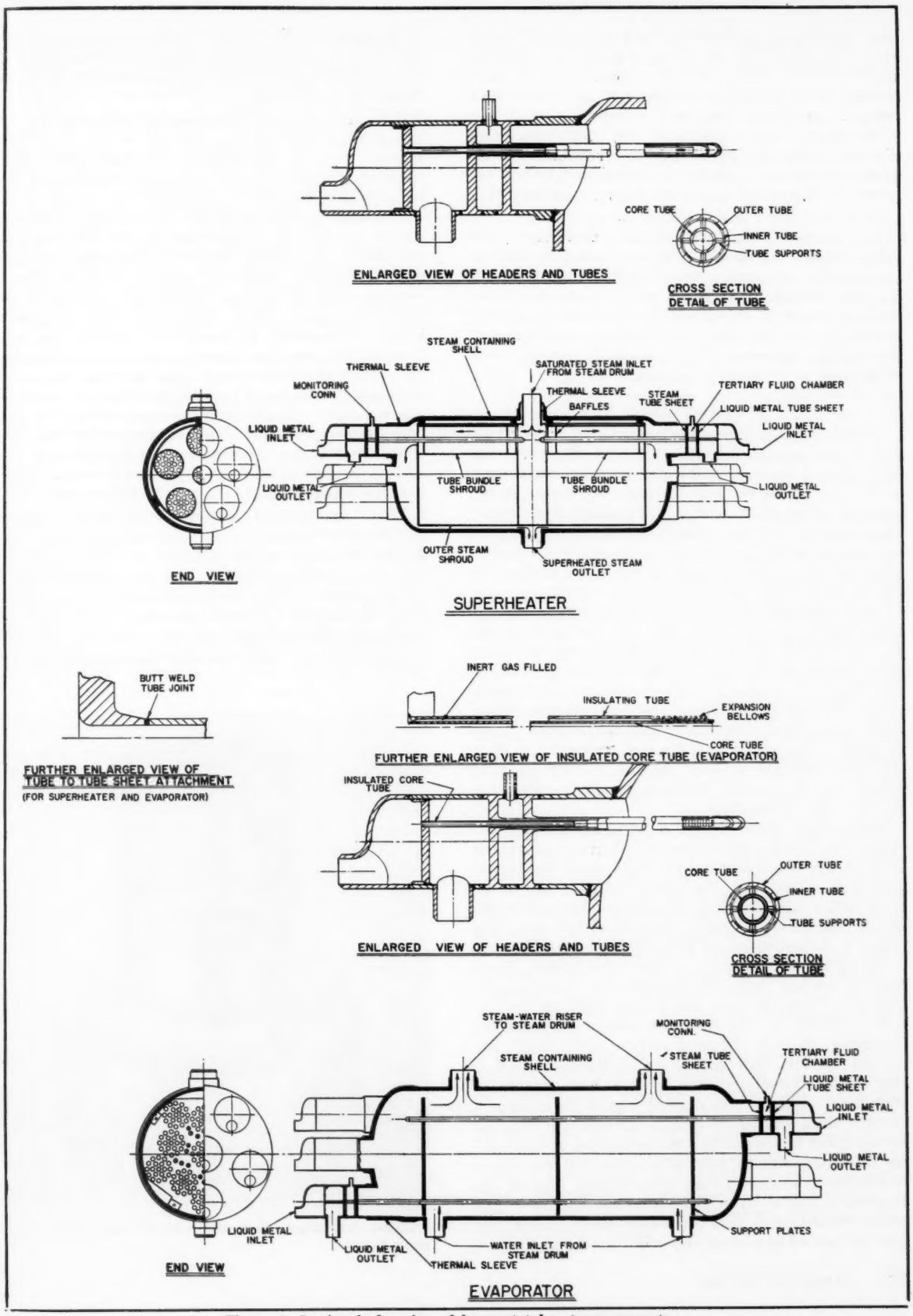


Figure 2. Sectional elevation of bayonet tube steam generator.

steel has been selected as a construction material. This is justified on the basis that it is a common superheater material though a lower alloy or even carbon steel might be satisfactory at a superheat temperature of 750 degrees F or less.

At least one reference (6) indicates that 2¼ CR-1 MO has good long time resistance to sodium at temperatures up to approximately 900 degrees F. There are corrosion tests under way that should contribute additional data.

By virtue of similar expansion coefficients, the combination of 2¼ CR-1 MO and carbon steel at attachments is much more compatible stresswise in the evaporator than, say, austenitic stainless steel and carbon steel. At elevated temperatures this becomes a major consideration. The same holds true in fabrication processes (for example, during stress relieving) as well as in operation.

CONFIGURATION

Sodium enters the superheater headers, or nozzles, flows through the core tubes, see Figures 1 and 2, is routed through a 180 degree turn whereupon it returns to the headers through the annuli in the bayonet tubes. Inlet and outlet sodium streams are separated by the pass plate that is located in a plane transverse to the longitudinal axis of the headers. It then follows a similar path through the evaporator and is directed to the liquid metal pumps.

This important advantage is achieved through the adoption of the bayonet tube: the flow pattern can be arranged so that the temperature drop across the tube sheets is that due to the difference between the water or steam and the annular liquid metal stream temperatures. Thus, the temperature difference across the tube sheets can be reduced by an amount equal to the liquid metal temperature drop and the thermal stresses in the containing tube sheets and associated junctions would be alleviated by the same proportion.

Steam flow through the superheater is also arranged so that the temperature difference across the tube sheets is reduced by the amount of the superheat that is added to the steam, because the saturated steam inlet nozzle is located on the mid-length of the superheater rather than at either end. The steam is superheated by routing the steam through a series of close-pitched orifice type baffles. Upon leaving the last baffle the superheated steam negotiates a 180 degree turn and passes through the annulus formed by the pressure vessel wall and the enclosing shroud. Several other advantages are gained by this flow route. An isothermal shell is one. It is appreciated that a very high degree of superheat in this arrangement would necessitate a thicker shell wall since design stresses are reduced by elevated temperatures. Nevertheless, it may still be advantageous to pay this price for the more favorable gradients across tube sheets and at the thermal sleeve to tube sheet junction, Figure 7. Another advantage is that the steam outlet connection can be located at almost any point on the shell.

Examination of Figure 2 shows how the complexity of the heat exchanger elements is increased by the double leakage barrier requirement discussed earlier in this paper.

The multi-header arrangement provides for isolating approximately ten percent of the total heat transfer area. In the event of the malfunction of an individual bayonet tube the bundle containing that tube probably would be isolated. This would be accomplished by blanking off the sodium inlet and outlet lines of the header serving the affected bundle and its associated bundle in the other component. Continued operation with a cold bundle is feasible because the tube sheets are attached to the shell by means of a cylindrical thermal sleeve. When it becomes necessary to replace the heat transfer element the bundle is parted from the shell by cutting the attachment weld between the steam (inboard) tube sheet lip and the thermal sleeve. A spare bundle would then be inserted and a new attachment provided. The unique tube to tube sheet attachment, see Figure 3, precludes the possibility of individual tube replacement without first removing the bundle in which it is located.

There are several handicaps associated with the multiheader steam generator arrangement: the larger pressure vessel required to encompass the less compact tube layout; and the complex liquid metal piping serving the individual headers. However, depending on the application these may not represent disadvantages. In any event they become negligible when the resulting advantages are re-

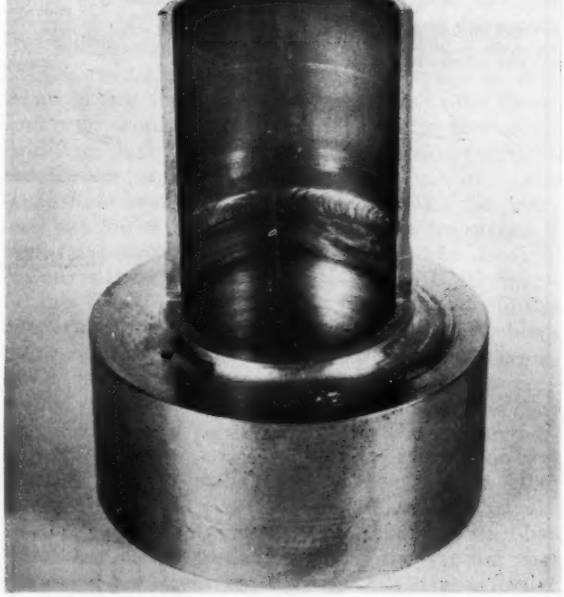


Figure 3. Partially sectioned tube to tube sheet attachment sample.

viewed and given appropriate consideration. The ability to isolate and replace a portion of the heat transfer surface without necessarily discontinuing steam generating operation is certainly a significant advantage. Moreover, the fabrication and quality control of small diameter tube bundles with thin tube sheets is greatly simplified.

The advantages of the tube to tube sheet attachment illustrated by Figure 3 over the conventional expanded seal welded tube to tube sheet joint in liquid metal heat exchangers are listed:

1. The structural dependability of the attachment is a function of a butt weld whose integrity can be confirmed by radiographic examination,
2. the stress concentration factor at the junction is minimized by the generous fillet in the tube attachment lip,
3. thermal stresses at junction minimized by gradual change in heat flux,
4. structural reliability is not impaired by subsequent stress relieving operation, and
5. crevices are non-existent, thus impurities are not concentrated and crevice corrosion is not a factor.

Further it is possible to realize a much more compact tube layout with the welding procedure* employed whereby the electrode approach is from the inside of the elements being joined; currently employed external welding procedures ordinarily require a greater tube pitch in order to provide adequate welding accessibility and quality control. For the same reason the interior approach also permits fabricating larger tube bundles than are otherwise practical. It should be noted that at this writing this method is limited to moderate diameter tubing, approximately one inch inside diameter or greater.

Consistent with the philosophy of maximum structural integrity of the tube to tube sheet junction is the use of integrally forged tube attachment lips on the tube sheets. This feature is desirable in order to provide a smooth transition in metal flow lines at the tube to tube sheet attachment. That is, the grain flow in the attachment lip is parallel to the main axis of the tubing and thus the strength of the junction is improved. The special geometry is obtained by a closed die forge process. Economic considerations of the process necessitate that small, relatively thin tube sheets be used.

Bayonet tube application in systems with large tube fluid temperature ranges, such as that prevailing in the subject steam generator, is feasible through the adoption of the insulated core tube.† This device, illustrated by Figure 1, is simply an arrangement of two concentric tubes containing an insulating medium, such as an inert gas in the annulus. The expansion bellows accommodates differential axial expansion between the tubular elements. An entire bundle of core tubes might be served by a single larger bellows located between a set of double pass plates; one possible objection to this arrangement, however, is that it leads to larger diameter headers. Disadvantages to the individually served bellows design are the increased pressure drop and complexity of construction and inspection.

A bimetallic construction in which the outer tube possesses a higher expansion coefficient than the inner tube might also be considered as an alternative means for offsetting the differential thermal movement. Metallurgical and welding problems might be encountered in some bimetallic designs.

Of course, with a high thermal conductivity fluid in the tubes it is mandatory that the tube ends be sealed in order that the insulation be effective. Highest quality attachment welds between the concentric tube ends are required to assure high performance operation. In the event of the loss of the insulating value of several core tubes, say less than five percent of the total heat transfer surface, the effect on performance, for practical purposes, is negligible. However, since the temperature of the liquid metal leaving the annulus of such tubes will be increased over that prevailing in the balance of the tubes additional thermal stresses are imposed on the tubes in the region between the double tube sheets, see Figure 1.

A solid wall core tube of low conductivity as well as a solid insulation filled annulus have been considered as a reheat prevention means. The latter was proposed so that in the event of sodium leakage into the insulating annulus the insulation value would not be appreciably impaired. The thermal conductivity of the annulus filler material should be low in order to be an effective insulation. If the conductivity of the filler, k, is not less than approximately 5 Btu/(hr) (sq. ft) (deg. F per ft) it would probably be more advantageous economically, at least, to use a solid core tube wall of, say, Invar or some other low conductivity, mechanical impact resistant material. Of course, the penalty involved in the utilization of such a relatively high conductivity material as compared to air ($k = 0.03$) is the reduced thermal effectiveness. While it is desirable to use a ceramic as such a filler the commercially available ceramics possessing satisfactory thermal conductivity values deteriorate upon immersion in liquid sodium. It seems that the silicate binder is leached from the ceramic by liquid sodium. The carbides and pure oxides have very satisfactory resistance to sodium attack but have thermal conductivities too high for many applications. Wrapping thin flat tubing in the annulus has also been considered as a possible solution.

In cases where the overall temperature difference between the bulk temperatures of the fluids is approximately 200 degrees F or less, the differential expansion strains probably can be safely sustained by the tubes and special expansion absorbing means are not required. Special circumstances such as unusual transients or very frequent cycling operation may, nevertheless, necessitate such a provision in steam generators with temperature differences less than the above figure.

* Patents pending by Griscom-Russell Company
† U. S. Patent No. 2,665,556 issued to P. S. Otten, assigned to Griscom-Russell Co.

A relatively small number of suddenly applied temperature gradients, more commonly termed thermal shocks, may be capable of causing failure depending upon the nature of the components exposed to the shock. Such severe shocks are induced by rapid power fluctuations of a nuclear reactor utilizing a liquid metal coolant. A substantial sodium temperature rise is occasioned by the loss of power to the coolant pumps of the sodium-cooled nuclear reactor (5). A thermal shield system has been provided at the insulated core tube to core plate junction in the evaporator to protect the insulated core tube welds from such a temperature rise. The consequence of a failure of these welds has been discussed earlier in this paper. The superheater can be designed to attenuate thermal gradients by modifications to the core tube. A relatively thick core tube wall or a low thermal conductivity wall or a combination of both are examples of possible modifications. The geometry of the duplex tube joint is such that it should be better able to withstand thermal shocks. The relatively minor consequences of a failure of the core tube to core plate joint do not warrant the use of improved attachment at that location. That is, the principal effect of damage at this junction is the reduced thermal performance. Leakage across the joint does not have the catastrophic possibilities associated with it as does leakage at the duplex tube to tube sheet junction; hence, the different design.

To accommodate the strains that are induced by thermal loading special precautions are taken to provide a structure of the highest ductility. Some of the necessary precautions are listed:

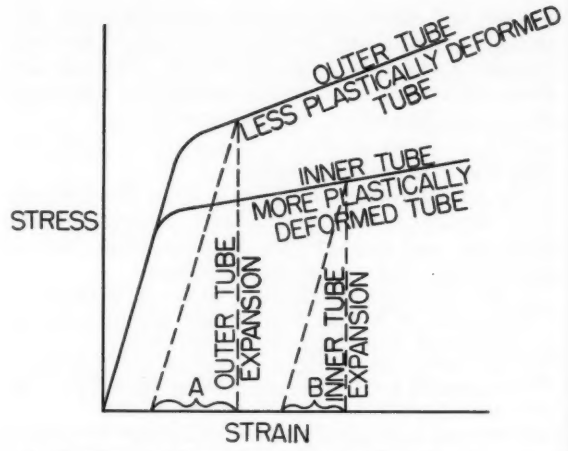
1. minimize stress concentrations,
2. procure good quality materials,
3. provide good weld design and procedures,
4. stress relieve welds, and
5. high standards of fabrication quality control.

Several of these are discussed in other portions of this paper.

The mechanical bond between the duplex tubes is achieved by a roller expansion procedure. In order to provide a backing against which to expand, thus assuring a minimum contact resistance, outer tubing of higher yield strength than the inner tubing was specified. With such a combination of strengths and minimum initial clearance between the concentric tubes prior to expanding a good bond can be achieved. This is accounted for by the greater elastic recovery of the outer tube as compared to that of the inner tube, see Figure 4. As noted previously the better the bond the less a factor is the thermal conductivity of the gaseous third fluid. Illustrations of satisfactory and unsatisfactory bonds or contacts are given by Figures 5 and 6, respectively.

Care must be exercised in the roller expansion process to obtain a relatively smooth expanded surface. Otherwise the tube side pressure drop is increased.

It is generally recognized that crevices have a tendency to be regions in which solids are concentrated. This, of course, promotes corrosion. Further, they act as "stress raisers" in some circumstances. It should be noted that the water and steam sides of the components under discussion are free of crevices; this is possible through the use of the unique tube to tube sheet and tube to tube cap attachments, and other special weld designs and processes. The regions in the header shell thermal sleeve where there is a relatively narrow gap between the peripheral tubes and the interior of the thermal sleeve, see Figure 7, should be flushed free of solid concentrations by internal recirculation of the boiling water.



A—Recovery of outer tube following expansion*
B—Recovery of inner tube following expansion
* Unrestrained recovery

Figure 4. Stress-Strain curve of duplex tubes.

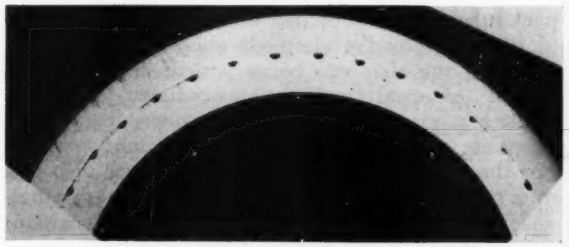


Figure 5. Example of good duplex tube heat transfer bond.

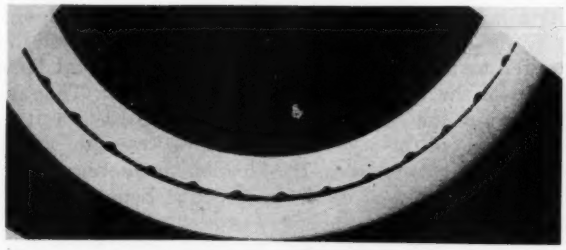


Figure 6. Example of poor duplex tube heat transfer bond.

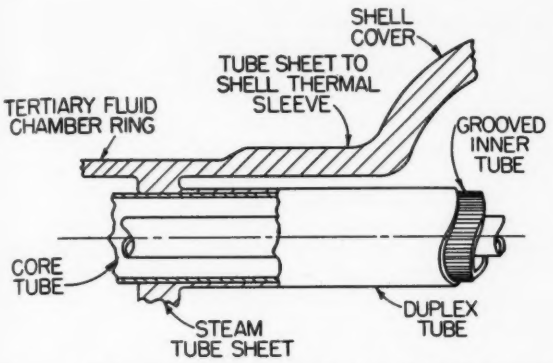


Figure 7. Enlarged detail of tube sheet to shell attachment.

In general, stress concentrations are minimized through the use of generous fillets, long tapers or gradual transitions between adjacent parts of dissimilar thickness, and weld designs and procedures which eliminate need for permanently installed backing rings. Thus, stress levels are reduced and the fatigue life of the steam generator is improved. Dolan (12) suggests other methods whereby stress concentrations are minimized or reduced.

STRUCTURAL ANALYSIS

General

Generally speaking, the thickness of pressure parts is determined by the rules in the ASME Power Boiler Code (13). The thickness of the double tube sheets was based on a modified TEMA (14) expression. Gravitational, mechanical shock, and thermal loads in addition to hydrostatic loads (both statically applied and fluctuating loads) were considered in some detail. Where design was a function of thermal loading recourse was had to the literature (15) and (16), and the standard texts (17), (18), and (19).

Thermal stresses present, perhaps, the major problem in the design of liquid metal heated steam generators. The steam generator under discussion eliminates certain regions where high stresses would normally be encountered; nevertheless, the large temperature differences discussed earlier produce thermal stresses which require special measures to alleviate.

The temperature difference across the elements of a particular steam generator being fixed, steady state thermal stresses can be reduced only through the use of:

1. Material with low product αE
2. Material with high thermal conductivity, k
3. Thin wall elements

Of course the use of carbon steel and 2¼ CR-1 MO in the subject steam generator represents an improvement in items 1 and 2 over a construction in austenitic stainless steel, for example.

Certainly, thin wall elements are more capable of withstanding rapid temperature changes (thermal shock) than are thick walls. The latter, if present in the structure, should be insulated against such transients by thin baffles. An inspection of the elastic equation for the thermal stress at the surface of a cylindrical element, away from edges, will indicate that the maximum transient thermal stresses are higher in thick wall elements:

$$\sigma_{max} = \frac{\alpha E}{1-\nu}(T - T_m) \quad \ldots\ldots\ldots\ldots\ldots (1)$$

T represents the temperature of the element surface exposed to the transient temperature and T_m represents the mean element wall temperature. Temperature T responds very rapidly to a temperature change for either a thin or thick wall. However, the mean wall temperature T_m in the thin wall follows the transient temperature more rapidly than does the thick wall T_m. Therefore, the quantity within the brackets is greater for a thick wall producing higher thermal stresses. For a more thorough treatment of thermal shock the reader is referred to Cheng (20), Tidball and Shrut (21), and Coffin and Fritz in the Liquid Metals Handbook (22).

Details

Several of the analyses may be of interest to the reader. The highlights of some of these are considered.

Header Cylinder—Pass Plate Junction

There is a steady-state temperature gradient in the axial direction of the cylinders at the pass plate which separates the inlet fluid from the outlet.

The thermal stresses in the cylinder will vary between wide limits depending upon the design of the attachment of the pass plate to the header cylinder. The most pessimistic case is where the attachment is through a ring which is assumed to be very rigid as compared with the cylinder and there is a step change in temperature at plane A—A. See Figure 8.

That the solution is well known is recognized; the contribution, if any, is the application of the solution.

The cylinder on either side of the pass plate can be assumed long since its product βl exceeds 5.0 The derivation is given in articles 81 and 82 of reference (17). Going directly to the result, the magnitudes of the uniformly distributed shearing

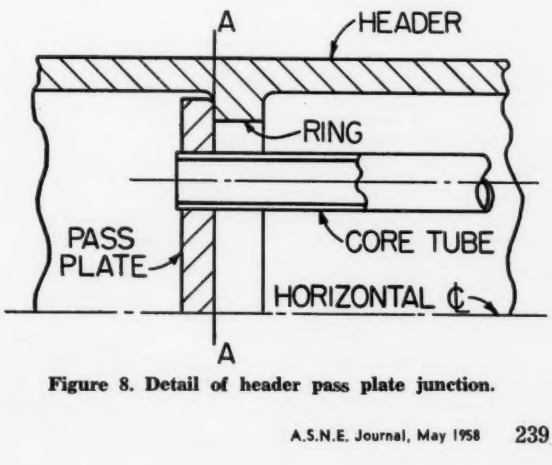


Figure 8. Detail of header pass plate junction.

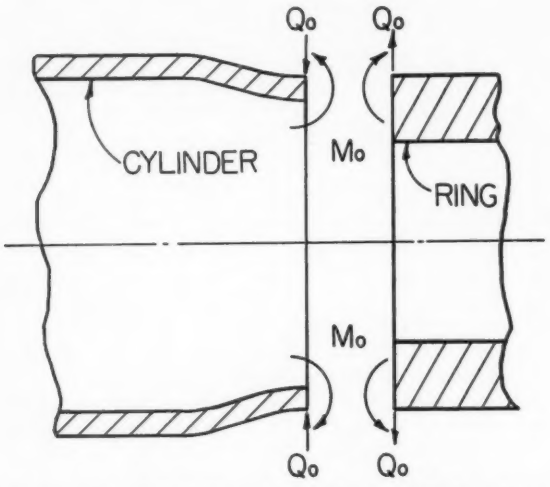


Figure 9. Analytical illustration of header cylinder at pass plate junction.

force, Q_o, and the bending moments, M_o, applied at the cylinder-ring junction, see Figure 9, are:

$$M_o = 2\beta^2 D\delta \quad (2)$$

$$Q_o = 4\beta^3 D\delta \quad (3)$$

The differential radial expansion, δ, at plane A—A were the cylinder at the junction not restrained equals $r_m \alpha \triangle T$. Inserting this value in expressions (2) and (3) and substituting them in Roark's (23) cases 10 and 11, Table XIII, results in the following equation for the maximum bending stress:

$$\sigma_z = 1.82\,\alpha\,E\,\triangle T \quad (4)$$

This stress occurs at the junction.

A more favorable situation can be achieved by minimizing the ring section. The most optimistic case, i.e., ring cross section is zero, for a step change in temperature results in a tangential bending stress which is also a maximum at the junction.

$$\sigma_\theta = 0.50\,\alpha\,E\,\triangle T \quad (5)$$

Expression (5) is obtained similarly to (4). If the temperature change can be spread over a distance and this gradient is linearized by means of a thermal shield, for example, the maximum stress can be further reduced to:

$$\sigma_z = 0.353\,\alpha\,E\frac{\triangle T}{l}[r_m\,y]^{1/2} \quad (6)$$

Fritz (15) presents a tabulation of thermal stresses and deformations which is a very helpful design tool.

Coexistent with thermal stresses are the stresses produced by hydrostatic pressure and nozzle loading. The latter were determined from Bijlaard (24).

The configuration finally adopted in the steam generator was developed on the basis of such considerations.

Saturated Steam Nozzle—Superheater Shell Junction

This junction and the steam tube sheet-thermal sleeve junction, are treated in a similar fashion. The temperature distribution is first determined. For the case in point a fin analogy is used in conjunction with a two dimensional field plot. The nozzle thermal sleeve length (see Figure 10) was established through a consideration of its effect upon the bending stresses at the nozzle-shell discontinuity. That is, the absence of such a device would produce a gradient approaching that indicated by curve A on Figure 11. However, it is common practice to install a thermal sleeve to attenuate the gradient. Such a profile is shown by curve B. The hyperbolic curve is obtained from the following well known expression

$$t = t_a - (t_i - t_o)\left[\cosh v - \frac{\sinh v}{\tanh v_1}\right] \quad (7)$$

For a long cylinder this can be written

$$t = t_a - (t_i - t_o)e^{-v} \quad (8)$$

When the temperature distribution is known the thermal stresses are computed from equations like those used in the analysis above. The maximum bending stress per reference (15) occurs at the junction and equals

$$\sigma_z = 1.41\,\alpha\,E\,m\,\triangle T[r_m\,y]^{1/2} \quad (9)$$

Added to this stress are the discontinuity pressure stress and the piping flexibility terminal stress. The former is also a maximum at the junction and has the value

$$\sigma_z = 1.82\,\frac{pr_m}{y} \quad (10)$$

The terminal stress may be significant depending upon the flexibility of the line. It is computed by conventional piping calculation methods.

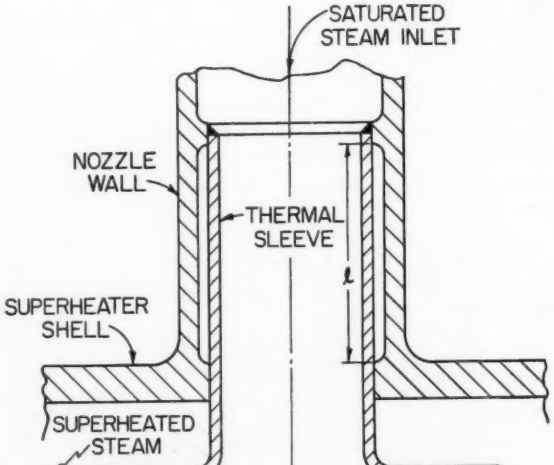


Figure 10. Superheater steam inlet nozzle.

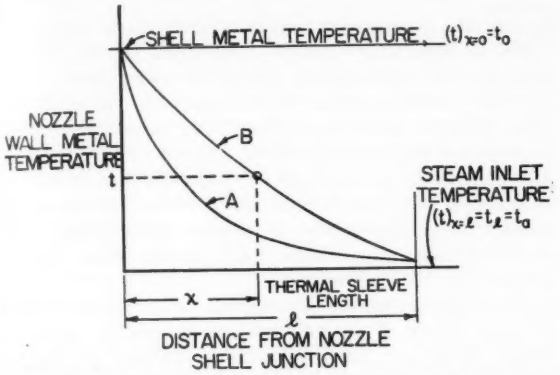


Figure 11. Temperature gradients in steam inlet nozzle of superheater.

Tertiary Fluid Chamber Ring

The stresses in the cylinder spacing the double tube sheets arise from hydrostatic and thermal loading. The tube sheets are assumed to be very rigid as compared to the cylinder.

In a long cylinder the conditions at one edge do not effect the opposite edge and conventional equations are employed. In a short cylinder recourse must be had to the general solution for radial deformation, see article 82 in reference (17), which contains four constants of integration.

The longitudinal bending stress induced by hydrostatic pressure has a maximum value at the ends of the ring where it joins the tube sheets and for a short cylinder is determined from the following equation:

$$\sigma_z = \frac{1.82\, p r_m}{y}\left[\frac{\sinh\beta l - \sin\beta l}{\sinh\beta l + \sin\beta l}\right] \quad \ldots\ldots\ldots\ldots (11)$$

For a long cylinder βl is large and the quantity within the brackets approaches unity. Thus, the value of the stress approaches that given by equation (10). Reference (17) tabulates values of the bracketed quantity.

The ring has a temperature gradient in the axial direction. The gradient is linear providing there is no heat transfer from the tubes and the tertiary fluid (assuming the exterior surface is insulated). In this case the bending stresses result from the restraint offered by the tube sheet. If heat is transferred to the ring the temperature at any transverse plane in the ring is given by expression (7) above. The gradient may be aggravated by such heat transfer resulting in increased bending stresses in the ring. The thermal loading at the ends of the cylinder is antisymmetrical while the hydrostatic loads are symmetrical. In the former the loading at one end of a short cylinder increases the longitudinal bending stresses at the opposite end and in the latter the stresses are reduced. Thus, thermal stresses in the ring can be alleviated by increasing the length of the ring. The longitudinal bending stress in a short cylinder with a linear axial gradient is a maximum at the ends of the ring and is calculated from the expression:

$$\sigma_z = 1.41\,\alpha E \frac{\triangle T}{l}[r_m y]^{1/2} F \quad \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

The term F can be considerated as a short cylinder factor. It equals

$$\frac{\cos^2\alpha'\sinh^2\alpha' + \sin^2\alpha'\cosh^2\alpha'}{\sinh\alpha'\cosh\alpha' - \sin\alpha'\cos\alpha'}$$

where $\alpha' = \frac{\beta l}{2}$. A tabulation of values to slide rule accuracy follows:

α'	F
0.2	7.50
0.4	3.75
0.6	2.51
0.8	1.90
1.0	1.54
1.2	1.31
1.4	1.17
1.6	1.08
1.8	1.02
2.0	1.00
2.5	1.00

In the case of long cylinders the factor F approaches unity and the maximum stress is given by the expression.

$$\sigma_z = 1.41\,\alpha E \frac{\triangle T}{l}[r_m y]^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (13)$$

In addition to these stresses another thermal stress is produced in the ring by the restraint of the differential axial expansion between the ring and the enclosed tubes. This is ordinarily handled by equating the strains and using Hooke's Law. This equation results:

$$\sigma_z = \frac{(\alpha_t E_t - \alpha_r E_r) n\,(r^2_{to} - r^2_{ti})\,E_t\,E_r}{E_t n (r^2_{to} - r^2_{ti}) + E_r\,(r^2_{ro} - r^2_{ri})} \quad \ldots\ldots\ldots (14)$$

For larger tube sheets the deformation of the tube sheets should be considered. The loading in the tubes can be determined using Gardner's fixed tube sheet analysis (25) or, for still greater accuracy, Yu's (26).

Evaluation

It is generally recognized that thermal stresses represent a strain input and are characterized as displacement type stresses, $\sigma = \frac{E\delta}{l}$ More conventional engineering stresses represent a load input, for example, hydrostatic pressure, and are usually described as load type stresses, $\sigma = \frac{P}{A}$

Calculated elastic stresses beyond the yield point of the metal do not materialize since plastic flow occurs. Plastic flow of the material will relieve displacement stresses. It is apparent that this is definitely not the case for load type stresses. However, cyclic operation in which plastic strain occurs may result in thermal stress fatigue failure depending upon the number of cycles, the amount of plastic strain occurring in a single cycle, the geometry of the material, and the material properties (27). Hence, strain becomes the criterion for mechanical

sufficiency in the event that calculated displacement stresses exceed the yield point.

It is also recognized that the dimension time has particular significance in strength evaluation. That is, stress is applied to the structural elements on a steady as well as a variable or fluctuating basis.

Displacement and load type stresses each consisting of steady and/or variable components occur in equipment of this nature. Therefore, several criteria for the acceptibility of the stresses and strains are utilized.

Steady Stress

The maximum shear theory by virture of its simplicity was selected as the most practical working tool with which to evaluate calculated steady stresses. Where the calculations indicated that steady *displacement* type stresses exceeded the allowable shear stresses shear strain limits were applied.

Variable Stress

Variable stress is considered to include the combination of a steady stress component Sm and a variable stress component Sv. A graphical representation by Soderberg (28) of the modified Goodman relationship (29) (30), more commonly referred to as the Goodman Diagram, was utilized to evaluate the combined stresses. A point on the straight line of this diagram is given by the equation

$$\frac{Sv}{Se} + \frac{Sm}{Sy} = 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

where Se and Sy represent the endurance limit and the yield point of the material at design temperature, respectively. Langer (31) suggests the endurance or fatigue limit should be obtained from the portion of the curve above the "knee" of the S-N diagram. This is justified on the basis that the number of thermal cycles to which the structure is subjected will fall within that region of the curve. Conventional endurance limits are based on numbers of cycles far in excess of those which might be contemplated in steam generators.

If the coordinates representing a stress condition fall above the straight line of the Goodman Diagram and the stresses are of the displacement type a similar approach utilizing strains can be employed.

FABRICATION

There are several fabrication considerations entering into design that influence structural integrity.

Small, relatively simple structural elements are incorporated throughout the entire steam generator so that manufacturing operations are eased. This makes higher quality workmanship possible as well as a more economical steam generator. Moreover, the economic advantage of repetitive fabrication operations with small tube bundles as compared to conventional procedures employed with large tube sheets which accommodate the entire tube layout should not be overlooked.

Good accessibility for welding production is also of importance if sound weldments are to be provided. This, too, assures a more ductile structure. The ductility requirement was discussed earlier in this paper. Stress relief anneal of all 2¼ Cr-1 MO welds as required by the ASME Code provides additional ductility.

QUALITY CONTROL

It was mentioned in an earlier section that it is necessary to provide good quality metal if maximum structural ductility is to be achieved. Several methods are employed to ensure that such material is procured. For example, ultrasonic testing of the raw material will reveal subsurface flaws which function as stress raisers. This inspection method is ordinarily limited to critical structural elements, e.g., tubes and tubesheets and other pressure parts because of the high costs incurred in testing. Generally speaking, all flaws greater than three percent of the wall thickness are cause for rejection. High quality control standards are another means of attaining a ductile structure. All welds in the subject generator are subjected to either a radiograph or dye penetrant examination to detect imperfections in the weldment. The primary tube joints are inspected by both processes. An isotopic thulium oxide applied internally is used in the radiographic inspection of both the tube to tube sheet and tube to tube cap attachment welds. Magnetic particle testing is frequently employed to supplement the above techniques.

It is well known that molten sodium can penetrate minute flaws or openings. The possible results of interleakage have already been discussed. Inspection of assemblies by means of a mass spectrometer will detect such leaks. The Liquid Metals Handbook (32) indicates that 0.01 micron cubic feet per hour leakage is usually the maximum allowable leak.

SUMMARY AND CONCLUSIONS

In order to provide the highest degree of structural integrity in a liquid metal heated steam generator it is first necessary to select a configuration that eliminates or minimizes as many of the critically stressed regions as possible. Assuming proper material specifications have been prescribed it is next necessary to perform a complete theoretical stress analysis of the unit, supplementing it with experimental stress analysis and model testing as required. Having completed these steps the attainment of a steam generator capable of reliable operation under the extreme conditions that are imposed on such equipment requires the procurement of highest quality material, painstaking fabrication of the best workmanship, and proper quality control standards.

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The contributions of many persons and organizations in all phases of the steam generator activity are gratefully acknowledged. R. S. Kukfa* and F. J. Mehringer† made outstanding contributions. The former is responsible for the tube to tube sheet attachment configuration and the latter observed that high strength outer tubing improves the heat transfer performance of the duplex tube. Among other contributors are A. W. Bedford*, J. D. Selby*, J. L. VanUllen,* and R. W. Dickinson.**

Development of the isotopic thulium oxide source configuration for radiographic examination of the tube welds is credited to Powell Richards# and his associates.

The special interior tube to tube sheet welding technique was originally proposed by Raymond Gardner, Project Engineer—Manufacturing, of the Griscom-Russell Company.

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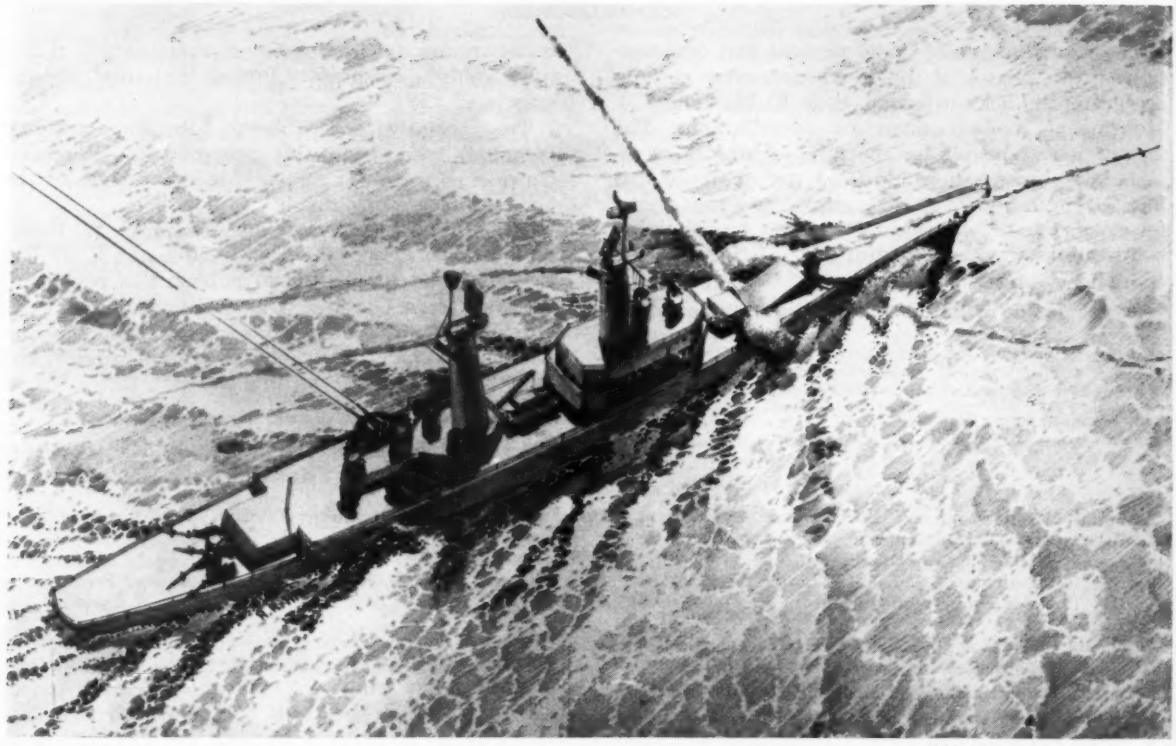

Official U. S. Navy Photograph

The distinct change in today's modern U. S. Navy can be seen in this artist's conception of the latest guided missile frigate (DLG). The drawing shows not only a change in profile but also the fore and aft location of the missile launchers and guidance systems. With the installation of guided missiles fore and aft, the ship's anti-submarine warfare and air defense capabilities are greatly increased.

Official U. S. Navy Photograph

Artist's conception of the Nuclear Powered Frigate (DLG (N))

"THE SHIPBUILDER & MARINE ENGINE-BUILDER"

TECHNICAL PROGRESS IN MARINE ENGINEERING DURING 1957

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Boilers and Steam Plant

From the orders which have been announced during 1957, it is clear that increasing interest is being shown in the range of working pressures between 600 and 950 psig for high-power steamships, and it is fortunate that, within the past few years, a method of water treatment had been developed which has certain advantages over the usual sodium-sulphite, caustic-soda treatment. For pressures below 650 psig sodium sulphite has, in general, been found to be a satisfactory feed-water deoxidant; but at pressures higher than this, it is known to decompose, yielding H_2S and/or SO_2, and from the experience of land boiler operators, such acid gas has been responsible for superheater-tube failures. Addition of sulphite increases the total dissolved solids in the boiler, and, to prevent carry-over, blowing-down has to be carried out at regular intervals, and it cannot be considered a fully satisfactory deoxidant for advanced conditions.

A very suitable oxygen scavenger is found in hydrazine (N_2H_4). Its use has been investigated in land boiler plants, and several papers have been published on its effect, during the past two or three years, in the Transactions of the American Society of Mechanical Engineers. One of the latest papers on the subject is by Mr. W. F. Stones, entitled "The Use of Hydrazine as an Oxygen Scavenger in High-pressure Boilers," and printed in *Chemistry and Industry* (2nd February, 1957). Pure hydrazine is a colorless liquid which boils at 236° F and freezes at 35.5° F, and is available in various strengths of from 40 to 64 per cent of hydrazine. It is a strong reducing agent and reacts readily with oxygen in alkaline solutions.

Probably the most important property of hydrazine is the fact that its decomposition and oxidation products do not increase the total dissolved solids content of the boiler water or give acidic reactions,

$$N_2H_4+O_2\rightarrow 2H_2O+N_2$$

and excess hydrazine decomposes to ammonia (providing its own alkalinity) and nitrogen as

$$3N_2H_4\rightarrow 4NH_3+N_2.$$

One pound of oxygen requires one pound of hydrazine for its removal, while, alternatively, 7.9 lb. of sodium sulphite is required (the whole of the oxidation products adding to the total of dissolved solids).

The author gives the record of full-scale tests carried out on two boilers, designed for a working pressure of 625 psig at 865° F. The one boiler was given sufficient sodium sulphite to maintain a residual of 40-60 p.p.m. in the boiler water and caustic soda to maintain a pH of at least 8.4 in the feed water. The other was dosed with hydrazine 100 per cent in excess of the oxygen content of the water at the feed pump, and, until such time as the ammonia concentration built up to give a pH of at least 8.4 in the feed, caustic soda was added with the diluted hydrazine solution. The caustic-soda addition was discontinued after about two or three weeks, by which time residual hydrazine could be detected. The pH of the condensate from the boiler with normal sulphite treatment was usually of the order of 6.8, whereas the condensate from the boiler treated with hydrazine had a pH about 9.0. After five months' steaming, this latter boiler was opened up and found to be in excellent condition, with much less debris than usual, and all later experience has confirmed this.

Analysis of records indicated that, in the presence of low concentrations of oxygen and carbon dioxide, the ammonia formed by the decomposition of excess hydrazine was effective in reducing the amount of metal pick-up. The ammonia was carried over with the steam, through the turbine and into the con-

densate, thus maintaining the high pH in the feedline recorded in the foregoing.

Further experiments, using only 50 per cent excess hydrazine, gave equal success with oxygen removal and reduction of metal pick-up, and yielded a lower concentration in the steam; initial dosing with 100 per cent excess hydrazine was necessary for the first fortnight, as before, in order to establish an effective residual concentration. Protection of boilers during "stand-by" periods can be obtained by injecting sufficient hydrazine to give 10 p.p.m. in the boiler water, directly into the boiler drum, while there is still sufficient circulation available to disperse the reagent. Ammonia formed by decomposition of hydrazine will be evolved and produce an alkaline condensate in the superheater.

The author has used this method for over two years and proved it most effective. The cost of the 50 per cent excess hydrazine treatment was found to be only 24 per cent more than the standard sulphite treatment, but the increased availability and reduced maintenance offset this excess many times over.

Some of the difficulties in hydrazine treatment are mentioned, such as that 40 per cent solution of hydrazine can react vigorously with strong oxidizing agents, but at room temperature, its rate of reaction with oxygen is slow. It should be kept well-stoppered and in a cool, dry place. It is an irritant and can cause dermatitis, and should, therefore, be handled with rubber gloves. Goggles should be worn to protect the eyes; the vapor is toxic and should not be inhaled. On the whole, 40 per cent solution of hydrazide presents no greater problem in handling than does dilute caustic-soda solution.

The usual conductivity method for detection of leakage of sea-water into the condensate is made a little more complex. With sulphite as a deoxidant, no operational difficulties are experienced, provided the excess in the boiler water does not exceed 60 p.p.m., and a reading of 3 dionic units or above usually indicates condenser leakage. However, because of the ammonia concentration due to hydrazine treatment, the conductivity from a leak-free condenser is between 8 and 12 dionic units. The difficulty is overcome by interposing a cation exchange column between the sampling point and the dionic cell. This column, while removing the conductivity due to ammonia, increases the sensitivity of the instrument in the event of a condenser leak, because of the conversion of neutral inorganic salts (*e.g.*, NaCl) to their corresponding acids.

For the determination of hydrazine in boiler water, a 50-ml. sample is mixed with 2.5 ml. of reagent and compared in an absorptiometer against a blank, similarly prepared, using distilled water after allowing to stand 30 minutes. The concentration of hydrazine in the boiler water is then read off from the calibration curve. Concentrations as low as 0.002 p.p.m. can be easily detected by this method. Dilute solutions of hydrazine in neutral solution react very slowly with oxygen at room temperature, and thus there is no need for elaborate precautions to exclude air, once the test is started. However, in the presence of alkalinity, the oxidation rate increases, and thus boiler-water samples should be taken in sealed flasks and the hydrazine residual determination should be commenced immediately. Exposure of samples to air, even for periods of less than one minute, results in low figures for residual hydrazine.

At the other end of boiler practice are the Scotch boilers using raw water, together with some sea-water as make-up. Particulars of a suitable water treatment, and suggestions for protection, are given in two papers presented to the Institute of Marine Engineers in February, 1957, under the general title of "Corrosion in Scotch Marine Boilers." The authors of Part I., "Model Boiler Tests on the Corrosion of Mild-steel Tubes in Highly Saline Waters," were Mr. F. Wormwell, Mr. G. Butler, and Mr. J. G. Beynon; while Part II., "Model Boiler Tests on the Influence of the Copper Content of the Steel on the Corrosion of Tubes in Artificial Sea-water," was written by Mr. G. Butler and Mr. H. C. K. Ison. Model boilers were used to carry out qualitative and semi-quantitative experiments on the corrosion of fire tubes in conditions simulating those in some Scotch boilers. Wrought iron tubes used to have a life of 15 to 20 years; but, since wrought-iron tubes are no longer manufactured, mild-steel tubes have been used and have been frequently subject to rapid and dangerous pitting corrosion attack. The work reported in these two papers was undertaken at the request of the British Shipbuilding Research Association.

The depth of pitting on mild-steel boiler tubes in distilled water with sea-water addition was found to increase with the density of the mixture. Increasing the oxygen concentration in the feed water from 4 ml. to 15 ml. per liter also increased the depth and extent of pitting. With a density in excess of 1/64 (*i.e.*, 2½ oz. per gallon), the water was found to be acid under operating conditions. Depth of pitting was markedly reduced by adding sufficient sodium carbonate to the feed to make the boiler water alkaline, although measurable pitting was still obtained with water of density of 1/32 (5 oz. per gallon). Under these conditions, an increase of oxygen concentration in feed water from 4 ml. to 15 ml. per liter does not produce any increase in depth of pitting. Some evidence was obtained that small amounts of copper in the steel reduce the likelihood of deep pitting, and it appeared that removal of mill-scale by grit-blasting or pickling did not improve the corrosion resistance of the tubes.

The experiments reported in Part II of the paper showed that with steels containing from less than 0.01 per cent copper to 0.20 per cent, the presence of the copper had a valuable effect in reducing the

severity of pitting of the tubes in the acid conditions that can develop in a boiler with untreated sea-water make-up. Of 66 tubes with a copper content greater than 0.1 per cent, tested with concentrations of 4 and 15 ml. per liter in the feed water, only one tube was pitted to a depth as great as 30 mils. in the standard eight weeks' test. Of 42 tubes with a copper content of less than 0.05 per cent, 10 were severely pitted, five being actually perforated, and in all, 18 had pits deeper than 30 mils. When the pH of the boiler water was maintained at an alkaline value, the pitting was slight, and it was not diminished by copper in the steel. The opinion is given that copper appears to stabilize the original mill-scale, pitting, when it occurs, being largely localized at breaks in this scale.

Recent controlled tests carried out by Mr. W. F. Harlow and reported to the American Society of Mechanical Engineers, in paper No. 56-A-159, entitled "Formation of Sulphuric Acid in Boiler Flue Gases," confirm that the formation of sulphuric acid in the flue gases of high-duty boilers arises from the oxidation of sulphur to sulphur trioxide by surface catalysis, mainly on the heating tubes and particularly in the superheater. The amount of sulphur trioxide formed during combustion is negligible, and, thus, measures aimed at restricting the catalytic action were sought. Both metallurgical coatings and chemical-spray surface treatments have been tried in a test apparatus. Of various metallurgical coatings tried, aluminum ethyl silicate gave the most promising result. The inhibiting effect of a chemical-spray of a solution of commercial soda ash lasted up to 556 hours.

In the test rig, the rates of formation of sulphuric acid had been purposely and artificially increased to reduce duration of tests, and the author considers that the duration of inhibition in an actual boiler would be increased up to 5,500 hours. Although the aluminum ethyl silicate gave protection for a longer period than the soda-ash spray, the latter is preferred, as it is more easily reapplied. Any surface treatment should be applied to all the boiler heating surface ahead of, and including, the superheater.

A new residual fuel-oil improver, Amber Desulfirol (S.S.R. 509), has been introduced by the Amber Chemical Co., Ltd., for the purpose of countering incomplete combustion and sulphur corrosion. The product has been developed in France, and it is claimed that the addition of one part per thousand of the product (*i.e.*, 2¼ lb./ton of fuel) to residual oil can reduce sulphur corrosion by between 50 and 75 per cent, improve conditions of combustion and inhibit the formation of sludge. It is stated that the additive, which is a safe self-mixing liquid, also prevents the oxidation of sulphur dioxide to sulphur trioxide.

A number of case histories of industrial boilers are quoted, and tests have also been carried out on board the *Bristol Queen,* which has a double-ended Scotch-type boiler—working pressure 180 psig—fitted with the Clyde fuel system. Trials were made with and without the additive, and the Mono carbon-dioxide recorder used as the test instrument indicated a considerable increase of carbon-dioxide content in the flue gas; a reduction of 7½ per cent in fuel consumption was also recorded. Fuel-consumption trials carried out in the *Cardiff Queen,* in the fleet of the same owners (Messrs. P. & A. Campbell, Ltd.), resulted in a recorded reduction of 9½ per cent in fuel consumption.

An interesting counterpart to their aircraft gas-turbine combustion chamber has been designed by Messrs. Joseph Lucas, Ltd., for marine and industrial use as a self-contained, high rate of heat-release combustor or hot-gas generator. The equipment comprises preheaters for the heavier fuels, fuel pumps, fuel-flow control, sprayer control, and the air-cooled combustor and sprayer. A typical combustor gives a heat release of 6.1×10^6 BTU per hour with a gas temperature of 3,270° F; an air-cooled stainless-steel radiation shield ensures that the mild-steel outer casing remains relatively cool. Such units can be used for steam raising or for separately-fired superheaters, and can be readily attached to a boiler front. The equipment is described in an article which appeared in *The Shipbuilder and Marine Engine-builder* for May, 1957.

The conditions necessary to promote dropwise condensation in steam condensers are dealt with in an article by Mr. P. G. Morgan in the *Egineering and Boiler House Review* for March, 1957. As well as a high degree of surface smoothness, it is necessary to have a thin film of suitable fluid, which wets and spreads uniformly over the tube surface and which itself presents a non-wetting surface to steam and water droplets—such fluids being known as promoters. Other factors influencing the dropwise condensation mechanism are critical size of drop, area covered by drops per unit area of condensing surface, period between successive clearing of an area (sweeping time of the rolling drops) and surface finish. These points are dealt with, together with the effects of various promoter-metal combinations and non-condensing gases on heat transfer with dropwise condensation. It is concluded that there is now sufficient experimental data to enable a sound method of design of condensing surfaces to be developed, thus permitting higher rates of heat transfer, with consequent reduction of weight and size.

Diesel Engines

The paper entitled "Development of Pressure Charging," presented by Mr. R. W. Stuart Mitchell to the 1957 International Internal-combustion Engine Congress, held in Zurich, gives a description of the general principles of turbocharging, followed by discussion of (*a*) low-pressure systems as used on four-stroke cycle engines, (*b*) the development work

in hand on the turbo-charging of high-speed engines, and (c) the high-pressure turbo-charging of medium and large four-stroke cycle engines. The use of reaction turbines is considered as an alternative to the more usual impulse type. High-pressure turbo-charged engines actually in production are listed, and reference is made to the current intensive development work on the turbo-charging of two-stroke cycle engines.

From the survey, it is concluded that the low-pressure turbo-charged four-stroke cycle engine in the medium and large sizes, is completely established, and has become the conventional form of engine, with b.m.e.p. of the order of 120/125 psi, giving a 50 per cent increase in engine output when compared with the corresponding naturally-aspirated engine. Such an increase can be accommodated without radical change of design, as the pressures and thermal loading involved do not give rise to excessive strains and stresses.

Current development work in turbo-charging the medium and large four-stroke cycle engine is now being concentrated on what has come to be called high-pressure turbo-charging which promises increases in output of 100/120 per cent when compared with the naturally-aspirated engine. This means b.m.e.p. of the order of 200 psi and boost pressures of 18 psig, and the increased pressures and thermal loads involve the special design of the engine from the beginning.

To take full advantage of the high supercharge pressure, maximum cylinder pressures of the order of 1,500 psig must be accepted, which, in turn, lead to problems in the design of suitable entablatures and also of providing bearings which can carry loads of the order of 2,000-3,000 psi of projected area. Such bearing pressures are in excess of the fatigue strength of white-metal and numerous devices have been tried in attempts to produce a bearing with improved fatigue strength. Copper/lead bearings have been adapted widely in America and this country for duties above the fatigue limit of white-metal, and recent developments in powder metallurgy have made the sintered copper/lead bearing possible up to a 40 per cent lead content, with an even distribution of the lead and with a higher density than a cast copper/lead. Copper/lead functions well on hardened journals, but with steels under 300 B.N. it has been found necessary to run with bearing clearances greater than is normal with a white-metal bearing of the same size, in order to be able to pass greater quantities of oil for cooling and to help counteract the poorer "embeddability" of the copper/lead.

The increased thermal loading of the high-pressure turbo-charged engine makes it necessary to pay increased attention to the cooling of the piston in the vicinity of the top piston ring. Even under optimum piston-cooling conditions, the top ring still has to transmit a large proportion of the heat to the jacket cooling medium, and careful attention is being paid to the liner cooling arrangements in the vicinity of the T.D.C. position of the top ring, in order to ensure rapid heat flow and adequate cooling.

Fuel injection provides another problem for the highly turbo-charged engine. The injection period must be kept within reasonable limits and the driving gear must be kept within suitable proportions. With the normal type of jerk-pump injection, neither of these problems is amenable to easy or rapid solution and, consequently, alternative systems of fuel injection are receiving much research and study.

Mr. R. W. Stuart Mitchell gives a list of high-pressure turbo-charged four-stroke cycle engines that are in production. The M.A.N. (K.8V. 45/66) engine develops 466 B.H.P. per cylinder at 250 r.p.m. (piston speed, 1,080 ft./min.) with a b.m.e.p. of 230 psi. The Enterprise engine develops 480 B.H.P. per cylinder at 400 r.p.m. (piston speed, 1,400 ft./min.) with a b.m.e.p. of 200 psi; the Mirrlees (KVSS.16) engine develops 258 B.H.P. per cylinder at 428 r.p.m. (piston speed 1,284 ft./min.) with a b.m.e.p. of 150 psi; and the Admiralty (ASRI) engine develops 157.5 B.H.P. per cylinder at 1,000 r.p.m. (piston speed, 1,750 ft./min.) with a b.m.e.p. of 160 psi. The specific weight of the 16-cylinder Vee form is 18 lb. per B.H.P.

In his paper to the International Internal-combustion Engine Conference, in Zurich, on "The Effect of Pressure Charging on Stationary and Marine Plant," Mr. J. Calderwood points out that one incentive to the development of turbo-charging two-stroke cycle engines was provided by the new tonnage rules which permit much smaller engine-rooms. Before the large two-stroke cycle engine was available in the low-pressure turbo-charged range, there was increasing interest in geared propulsion with high-pressure-charged four-stroke cycle engines, both on consideration of price and space. The successful development of the low-pressure turbo-charged two-stroke cycle engine has largely leveled out this difference, and the advantages of the four-stroke cycle engine are not nearly so marked as they were. In the smaller marine field, the high pressure-charged four-stroke cycle engine competes strongly with the two-stroke cycle engine and has been used in increasing numbers recently, both for trawlers and coasters.

While it is perhaps a little early to say that the low-pressure turbo-charged two-stroke cycle engine is the conventional form of the engine at present, it looks as if it will certainly be true in the course of a few years. As with the four-stroke cycle engine, low-pressure supercharging can be accommodated without any radical change of design, and b.m.e.p. of 95/100 psi can be attained with normal level of exhaust-gas temperatures.

Meanwhile, research and development effort is being directed toward the high-pressure turbo-charging of the large two-stroke cycle engine and several

firms are aiming at a 2,500 S.H.P. per cylinder line. Under conditions of high supercharge, the kinetic energy in the exhaust blow-down is not likely to be sufficient for driving the turbine, and so, instead of the impulse-type turbo-chargers at present used, a constant-pressure system will be adopted, with a common exhaust manifold and a full admission reaction-type turbine.

An article entitled "Pressure-charging Cross- and Loop-scavenged Two-stroke Diesel Engines" appeared in the *Brown Boveri Review* for May, 1957, and analyzes the pressure charging of such engines, both by pulse and continuous pressure turbines.

A large Diesel engine has been built in Japan by the Hitachi Shipbuilding and Engineering Co., Ltd. It is a standard Burmeister & Wain turbo-charged two-stroke cycle engine of 12 cylinders, 740 mm. bore by 1,600 mm. stroke, with a maximum continuous output of 15,000 S.H.P. at 115 r.p.m. The engine has four Rateau G.T.S.58 turbo-chargers, each connected to four cylinders. The crankshaft is semi-built, with webs of cast steel and journals and pins of forged steel; it is 59 ft. long and weighs 103 tons. The total weight of the engine, excluding thrust block, is 565 tons.

A new Werkspoor two-stroke cycle engine has been developed and tested. It is a trunk-piston direct-reversing unit of six or eight cylinders, 450 mm. bore by 700 mm. stroke, intended for coasters and similar vessels. At 250 r.p.m. and with normal aspiration, the six-cylinder engine develops 1,800 S.H.P. and the eight-cylinder 2,400 S.H.P. They weigh 58 and 75 tons, respectively. The fuel consumption of the six-cylinder engine on trial is reported as 0.353 lb. per S.H.P.-hour, with a normal b.m.e.p. of 71 psi. In a supercharged condition, this is expected to be increased to 92.5 psi. The engine has uniflow scavenge, with piston-controled inlet ports in the cylinder, and two exhaust valves in each cylinder head. Each cylinder has its own scavenge pump driven from the main piston by levers and coupling rods.

An interesting Diesel-electric installation is fitted on board the 205-ft. trawler *Cape Trafalgar*. This vessel is equipped with four Mirrlees type-J.L.S.M.8 engines, which are low-pressure turbo-charged four-stroke cycle units, each with a continuous rating of 600 S.H.P. at 600 r.p.m. with a b.m.e.p. of 106.2 psi. Each engine is directly coupled to a 330-kw. 300-volt generator, excited from a separately belt-driven Metadyne exciter. The generators supply a double-armature propulsion motor continuously rated at 1,500 S.H.P. at 175 r.p.m. The trawler can operate with any one, two, three or all generators, and the 300-H.P. winch motor can be operated from any of the main generators. An auxiliary field is used when a generator is serving a winch. The normal control of main power is by bridge controller, but control can, of course, be transferred to the engine-room.

The regular use of residual fuel in the large Diesel engine is now accepted practice and work is continuing in an endeavor to reduce rates of ring and cylinder wear. A considerable reduction of both piston-ring and cylinder-liner wear has been reported as a result of using grooved piston rings in place of ordinary plain rings (*Shipbuilding and Shipping Record*, 23rd May, 1957; "Grooved Piston Rings for Opposed-piston Engines"). The groove, machined around an ordinary ring, has a semicircular profile of 1½-mm. radius and does not appear to have effectively weakened the ring. It is thought that the beneficial effect of the groove is due to improved distribution of lubricating oil round the liner.

In recent years, the use of colloidal graphite has been avoided in H.D. oils containing detergent and dispersive additives, because it was thought that the graphite would react with the additives and render them ineffective. Professor J. U. Augustin and Dr. Anna Maria D'Ans have investigated this problem and have reported their results in *Verein Deutscher Ingenieure* (Vol. 99), for the 1st March, 1957, and 11th May, 1957, under the title of "Kolloidaler Graphit und sein Einfluss auf Reibung und Schmierung, besonders in Verbrennungsmotoren" ("Colloidal Graphite and its Influence on Friction and Lubrication, especially in Internal-combustion Engines"). The authors discuss the mechanism of lubrication, with especial reference to internal-combustion engine cylinders, and lead on to explain that the lubricating properties of graphite are attributed to the lamellar structure of its crystals, and that the effectiveness of different varieties can be related to their anisotropic diamagnetism. Owing to the diamagnetic properties of colloidal graphite suspended in a lubricating oil, graphite particles are strongly adsorbed to the metallic surface, penetrating the Beilby layer to some extent, and are oriented with their lamellar slip planes parallel to the surface. This mechanism has been confirmed by micrographic studies with an electron microscope and such graphitized surfaces maintain excellent wear resistance up to temperatures of 1,100° F in normal atmospheres.

Graphite can be applied during manufacture by mechanical means and results in improved lubrication while running-in, but, owing to inadequate adhesion, it does not provide a satisfactory permanent coating. When applied by electrolytic methods or by means of a thermosetting plastic binder, graphite can be deposited in a homogeneous coating of high wear resistance. Various graphitized surfaces have been examined with the aid of an electron microscope, the results are quoted and the techniques employed are explained. A 100-hour engine trial has also been carried out by the authors, using an H.D. oil with graphite additive, and a regular record was kept of the electrolytic properties of the oil. It was found that the presence of the other

additives did not prevent the deposition of graphite, but they did encourage preferential deposition on particular materials.

Gas Turbines

At the current level of coolant temperatures in nuclear-reactor practice, it is clear that it is more attractive to generate power by steam turbines than by gas turbines, both on account of economy and of weight. It is not until coolant temperatures move into the range of 1,300° to 1,400° F, giving a maximum cycle temperature of 1,200° F, that the gross thermal efficiencies of steam and gas-turbine plant become similar, and it is at this point that the gas-turbine plant may show an advantage in overall weight. The position is stated very clearly in an article by Mr. F. J. Bayley in *Mechanical World* of January, 1957. It is unlikely, even with the postulated high temperature of operation, that gas turbines will supplant the already established steam turbine for land power plant, and this may even be the case for ship's machinery. Thus, most development is to be expected with gas turbines using conventional sources of heat, *viz.*, gas turbines burning fuel at constant pressure having rotary air compressors and those using free-piston type gas generators.

In the constant-pressure combustion gas turbine, the cooling of the gases to a temperature which is acceptable for turbine blading is done by heat transfer to diluting excess air, which has been previously compressed, thus reducing the top temperature of the cycle and necessitating the use of correspondingly larger compressors and turbines. The maximum attainable efficiency is reduced as the top temperature of the cycle is reduced. With the free-piston gasifier/exhaust gas-turbine combination, the only excess air required is that necessary to obtain satisfactory combustion in a highly supercharged Diesel cylinder, and the cooling which takes place due to the near adiabatic expansion of the gases contributes energy to the system and does not just represent a degradation of heat level. It is primarily for this reason that, with the free-piston gas-turbine combination, thermal efficiencies of the order of 40 per cent are attainable with turbine inlet conditions of 45 psig at 830° F. This is a better figure than that attainable by the constant-pressure combustion gas-turbine cycle with considerably more advanced turbine-inlet conditions, necessitating special and expensive materials for turbine manufacture.

In a paper entitled "Gas Generator Power Plants," published in connection with the 1957 International Internal-combustion Engine Congress in Zurich, Mr. R. W. Stuart Mitchell points out that the free-piston engine is the logical development of the highly-supercharged two-stroke engine cycle. The results of Sulzer research work on turbo-charging, reported some years ago, indicated that, when supercharging pressure was raised to six atmospheres, the shaft output was just equivalent to that absorbed by the compressor, so that the compressor could be driven by the engine and the exhaust turbine could be disconnected mechanically, separately installed and supply the whole of the external load. As the author pointed out, a scheme in which the engine crankshaft delivered no external power led to the development of the free-piston gas generator. Such an engine is, therefore, subject to some of the difficulties inherent in conditions of high rating and high supercharging. These conditions are indicated by the following figures for a G.S.34 free-piston gas generator, compression pressure 1,000 psig, maximum cylinder pressure 1,700 psig and a mean rubbing speed of 1,760 ft. per minute. Nevertheless, results which are reported later show that these arduous conditions are being successfully met. Experience indicates that the free-piston gasifier is not sensitive to fuel and that residual fuels up to 3,000 seconds Redwood No. 1 at 100° F have been successfully used, with little sign of deposits in cylinder parts.

The power output is primarily controlled by varying the quantity of fuel injected per cycle, thus varying the length of stroke by its effect on the O.D.P. and at the same time the interaction of the gas-delivery pressure, while the mean cushion pressure is used to control the I.D.P. A limit is imposed on the minimum stroke, by the necessity to uncover the scavenge ports, and such a limitation leads to a condition where the turbine cannot accept the whole output from the gasifier. Originally, at and below this load point (approximately 25 per cent full load), it was necessary to blow-off the excess gas to atmosphere, with a resulting adverse effect on part-load performance and fuel consumption.

A recent development, called "recirculation," involves the feed-back of hot compressed air from compressor delivery to compressor intake at the scavenge end, resulting in a displacement of the I.D.P. from the engine transverse center-line, increasing the compressor clearance volume, and resulting in a reduction of the delivery to the turbine per stroke. The rate of oscillation is also reduced, because the cushion cylinder pressure is reduced. Both effects are cumulative in reducing the gasifier output. Nevertheless, since gasifier efficiency falls off fairly rapidly for delivery pressures below 20 psig, it is preferable not to go below this figure. The same methods can be used to improve part load economy as are used for steam turbines, *viz.*, separation of the admission of the first stage of the turbine into two or more sectors, each being supplied from a gasifier, or by providing a full-load admission belt to the turbine at some point after the initial stages. Astern power can be provided in a variety of ways, some of which are mentioned later.

The operating results of the *Cantenac* and *Merig-*

nac are reported in the paper entitled "Some Problems in Design and Use of Free-piston Gas Generators on Board Ships," presented by Mr. A. Augustin-Normand, Jnr., and Mr. M. E. Barthalon to the Institution of Naval Architects in 1957.* It will be remembered that these two vessels are the first merchant ships to be equipped with free-piston gas-generator machinery and they have been at sea since February and October, 1954, respectively. Each vessel is equipped with two G.S.34 gasifier-turbine sets, both turbines being coupled through reduction gearing to the single propeller shaft. It was reported that, in approximately 2½ years of operation, the *Cantenac* was immobilized for only eight days and the *Merignac* for only four days, due to engine trouble. In the initial stages, piston-ring wear was a major problem and the life did not exceed 500 hours. Improvements in both material and design of rings, and development of improved lubricants by a major oil company, have now improved matters to the point where 2,500 hours are run between ring inspections.

It was reported that the maintenance in the *Cantenac* and *Merignac* had always been carried out on board ship, without it ever being necessary to take a gas generator out of the engine-room.

The installation in the modified "Liberty" ship *William Patterson* consists of six G.S.34 gasifiers, coupled together in two groups of three. Each group supplies an Alsthom six-stage turbine, and both turbines are coupled to the single-screw shaft, through reduction gearing, to provide 6,000 S.H.P. ahead, and the two-stage astern turbines (on the same shaft as the ahead turbine) provide 2,100 S.H.P. astern. The turbines develop full power at 5,500 r.p.m. on gas supplied at 44.4 psig and 850° F inlet temperature.

On test-bed trials, each gasifier developed 1,233 H.P. with a thermal efficiency of 41 per cent; the overall turbine efficiency was 85 per cent; piping losses were estimated at 1½ to 2 per cent; and the reduction-gear losses amounted, on test, to 3 per cent. A specific fuel consumption of 0.43 lb. per S.H.P.-hour was reported, using a bunker "C" fuel, which is understood to have been 3,000 seconds Redwood No. 1 at 100° F, with a specific gravity of 0.957, a sulphur content of 2.48 per cent and an ash content of 0.95 per cent. The total weight of propulsion machinery and accessories is quoted as 268,000 lb.

Hydraulically-operated valves direct the gas flow to the ahead or astern turbines, as required, or through both for maneuvering at low speed. This control system is linked with that for the fuel injection, so that a single handwheel can be used to maneuver each set. The gas generators are placed side by side, just forward of the turbines, and the centrifuges, pumps and other auxiliaries are accommodated in the wing spaces beside the turbines. The masking of the astern blading was successful in reducing its windage loss (while running ahead) to an acceptably low figure. Unfortunately, during a six-hour astern run at full power in the course of preliminary trials, the windage of the ahead-turbine blading resulted in an excessive temperature rise, and, to reduce this, the ahead-blade clearances have been enlarged, with a consequent disappointing increase in fuel consumption. There is no exhaust-gas boiler in the *William Patterson*. Future machinery installations of this type, at this power, will probably be equipped with such a boiler and would probably have but a single turbine.

It is reported that, after 18 months' or so service experience with the *William Patterson*, the American Maritime Commission may modify the installation to permit after-burning just before the turbine inlet, in order to increase the power output up to 8,000 S.H.P. It is understood that such a plant will be unidirectional and that a reversible-pitch propeller is to be fitted. Under such conditions, specific fuel consumption is likely to be 0.49 lb. per S.H.P.-hour.

The British ship, *Omara*, built in 1947, is being re-engined by Messrs. Alexander Stephen & Sons, Ltd., with a gas turbine driven by the output from four G.S.34 free-piston gasifiers. Separate ahead and astern turbines are being provided, each being unidirectional and flexibly coupled through hydraulic clutches to the reduction gearing. The six-stage reaction type ahead turbine runs at 6,800 r.p.m. and delivers 4,000 S.H.P. to the propeller shaft at 110 r.p.m. Yet other orders have been placed for free-piston gas-generator exhaust-turbine sets, one for a 2,500-S.H.P. set and another for a 7,000 S.H.P. set.

The performance of these pioneer installations will be followed with keen interest and it is greatly to be hoped that the expected reliability and economy will be attained. If they are successfully established, then the other valuable attributes of this type of machinery can be fully exploited. The machinery is comparatively light and vibrationless, the gasifiers can be mounted on a platform above the turbine, if required, and full advantage can be taken of the new tonnage regulations to increase cargo-carrying space. Furthermore, in multiple gasifier installations, the ability to carry out a maintenance schedule whether the ship is at sea or in port can greatly help in the economic use of spares.

The *John Sergeant*, a sister ship of the *William Patterson* is, of course, engined with a classical-type constant-pressure combustion gas-turbine installation having two shafts and working on a regenerative open cycle, and has now had many months of successful sea-going operation. The results of the trials and maiden voyage of the *John Sergeant* are given by Mr. J. J. McMullen in a paper read before

* Reprinted in August 1957 JOURNAL.

the American Society of Naval Architects and Marine Engineers, in May, 1957, and before the Institute of Marine Engineers in December, 1957. The high-pressure turbine driving the compressor is designed to work with an inlet temperature of 1,450°F at 55.45 psig and to exhaust at 950° F, the low-pressure turbine accepting the gas at this temperature and exhausting at 890° F with a pressure of 0.40 psig. Besides the regenerative heating of the combustion air, the exhaust gas is used to generate 5,760 lb. per hour of saturated steam at 207 psig in a waste-heat boiler, 3,200 lb. per hour of which is also superheated to 543° F (by exhaust gas) for the turbo generation of 135 kw. From the l.-p. turbine. exhaust, the gases first traverse the superheater, losing only about 4.5 degrees of temperature, thence they pass through the regenerator and finally through the waste-heat boiler, from which they are discharged at 490° F. By-passes are arranged around the regenerator and waste-heat boiler to give flexibility of control. The test figures for the fuel consumption at 6,000 S.H.P. have been previously quoted at 0.5224 lb. per S.H.P.-hour and 0.5144 lb. per S.H.P.-hour at 7,000 S.H.P., at which powers all steam requirements are met from waste-heat generation, so that these figures represent overall consumption as well.

Maneuvering and power control have been found to be very satisfactory. The reversible-pitch propeller takes eight seconds to go from full-ahead pitch to full-astern pitch, and full-astern torque can be developed within as little as 18 seconds from commencement of reversal; under such conditions, the head reach of the *John Sergeant* from 17.1 knots at 8,000 tons displacement was 2,330 ft.

The Shell tanker *Auris* is being re-engined with gas-turbine machinery developing 5,500 S.H.P. and coupled to a fixed-blade propeller through mechanical gearing, hydraulic coupling and a Pametrada astern-torque converter. The installation is specifically designed to be capable of using any commercial grade of boiler fuel. To avoid excessive ash deposits, the inlet temperature is limited to 1,250° F and the adverse effects on efficiency of such deposits as occur are limited by using a multi-stage design with widely-pitched blades. Close pitching is a feature inseparable from turbines with only a few stages, and while such turbines, usually of relatively light construction, have many advantages over heavier multi-stage designs with respect to size, weight and the rapidity with which they can be started and put on load, they are inherently more sensitive to deposit formation.

In the *John Sergeant*, the two turbines each consist of a single-stage, the inlet temperature to the h.-p. turbine being 1,450° F, as noted in the foregoing, so that the ill-effects of extended running on residual fuels will be expected to be more marked. Arrangements are provided for washing and centrifuging to remove any sodium present and adding magnesium sulphate (Epsom salts) to inhibit high-temperature corrosion.

The *Auris* will probably use some similar pretreatment of low-grade fuels, and will supplement this with the methods of removing such ash deposits as occur by the methods developed and proved on the initial installation. The availability of the *Auris* machinery must be very high indeed, for not only is the time in either the loading or the discharging port less than two days, but the main turbine is to be used to supply power for pumping out cargo, and will, therefore, be available for maintenance at the loading port only. The actual results and knowledge of the grades of fuel that can be successfully burned in these two vessels will be of great interest. It is hoped that the viscosity figure, at least, will be quoted to denote grades of fuel, rather than the general term "bunker C," which has even been known to cover an oil having low ash and sulphur content and a viscosity approaching 100 seconds Redwood No. 1 at 100° F.

The first gas turbine to be adopted by the Admiralty for a main generator set in a major warship, H.M.S. *Cumberland*, was recently announced. It is a standard Ruston-Hornsby, Mark T.A., gas turbine directly coupled to a three-phase, 440 volts, 60 cycles/second, A.C. alternator, rated at 750 kw. It operates on a simple open cycle, is self-cooled and burns Diesel fuel oil. Arrangements are incorporated so that the compressor blades can be cleaned without dismantling, *viz.*, a water spray to wash off salt collected while at sea, and a paraffin wash to remove industrial fouling while in port; both are sprayed-in at the air intake. The following control requirements have been met:—For load changes of 25 per cent of full rated load, speed variation not to exceed 2½ per cent, momentary voltage change not to exceed 15 per cent (transient) and to return and remain at ± 1 per cent of set voltage within 0.5 second. They were met by fitting a Ruston P.2 limiter and a B.T.H. Magnastat. The presence of the gas turbo-alternator permits the complete shut down of boilers in harbor, and gives a simple and light installation free from vibration.

Nuclear Power

The undernoted papers have been referred to for the information that follows:—

(1) "Nuclear Power for Propulsion of Merchant Ships," by Mr. S. Livingston Smith and Mr. J. E. Richards (Transactions of the Institution of Engineers and Shipbuilders in Scotland, 1957.) *

(2) "Nuclear Propulsion of Ships," by Sir Christopher Hinton and Mr. R. V. Moore (Transactions of the Institute of Marine Engineers, 1957.)

(3) "Closed-cycle Gas-turbine Nuclear Propulsion Plants," by Mr. R. P. Giblon and Mr. G. H.

* Reprinted in the February 1958 Journal.

Kurz. (Transactions of the American Society of Naval Architects and Marine Engineers, 1957.)

(4) "Gas Coolant for Nuclear Reactors," by Mr. M. Silverberg (Second Nuclear Engineering and Science Conference; American Society of Mechanical Engineers, 1957.)

(5) "Fluid-fuel Reactors for Nuclear Merchant Ships," by Mr. Cecil B. Ellis. (Transactions of the American Society of Naval Architects and Marine Engineers, 1957.)

(6) "Some Problems in the Application of Nuclear Propulsion to Naval Vessels," by RADM H. G. Rickover, U.S.N., Captain J. M. Dunford, U.S.N., Mr. Theodore Rockwell III., LCDR. W. C. Barnes, U.S.N., and Mr. Milton Shaw. (Transactions of the American Society of Naval Architects and Marine Engineers, 1957.)

(7) "Materials Problems in Nuclear Reactors," by Mr. C. O. Smith (JOURNAL of the American Society of Naval Engineers, February 1957.)

The Institute of Marine Engineers, Institution of Naval Architects, Institution of Engineers and Shipbuilders in Scotland and North-East Coast Institution of Engineers and Shipbuilders have formed a Joint Nuclear Marine Propulsion Panel for the purpose of stimulating and facilitating the presentation and discussion of information regarding the application of nuclear power to marine propulsion. No. 1 of the Journal appeared in April, 1957, and contained a glossary of the terms used in nuclear physics, together with a brief description of some different types of nuclear reactors. The paper by Mr. C. D. Boadle on "Some Safety Considerations of Nuclear Power Plants," first presented to the North-East Coast Institution of Engineers and Shipbuilders in 1956, was also reprinted. No. 2 was issued in November, 1957, the principal feature being the Institute of Marine Engineers' Lloyd's Register Lecture for Juniors, "An Introduction to Nuclear Power," by Mr. P. T. Fletcher, first presented to the Institute in March, 1957. Although designated a lecture for junior members, it nevertheless forms an interesting and valuable introduction to the subject of nuclear power.

For marine application, weight and space per horse-power must be reduced well below that obtaining in land practice. In search of this achievement, a primary aim is the abstraction of heat at as high a rate and at as high a temperature as possible from a given volume of core. This implies small cores and high-temperature materials, giving rise to increased leakage and absorption of neutrons. To off-set this, the production of neutrons must be increased by the use of enriched fuel which greatly raises fuel costs. It is therefore seen that, for marine application, the choice of reactor and its most economical size depends on the balance between economic effect of falling weight per H.P. with rising cost of fuel per H.P.-hr. Almost 100 per cent pure fissile material is used in the *Nautilus* reactor, whereas, at the other extreme, Calder Hall reactors use natural uranium, only 0.7 per cent of which is fissile. At the present time, supplies of enriched fuel are strictly limited and very expensive in Britain. The United States is prepared, under certain conditions, to sell enriched fuel to overseas countries at a price which corresponds, roughly, to the cost of natural uranium plus about £6 for each gram (about £2,700 per lb.) of added uranium-235. It is possible to buy natural uranium and also heavy water (at about £20,000 per ton) from the United States.

In reference (1) the authors have studied the permissible cost under British economic conditions of nuclear propulsion of a tanker of 47,000 tons deadweight. Such tankers are likely to be in demand during the coming years, and the authors have examined the possibility of using a gas-cooled heavy-water moderated reactor, burning natural uranium, as a heat source for a steam-turbine installation for their propulsion. The method adopted in their study, which was carried out by the British Shipbuilding Research Association in cooperation with tanker owners, was to compare the costs of transporting oil from the Middle East to the United Kingdom in a conventional tanker and in a nuclear-propelled tanker of the same horse-power. For the nuclear ship, the calculations have been made for (*a*) a range of nuclear fuel costs, including fuel investment charge and (*b*) a range of figures by which the machinery and associated structural weight might be regarded as additional to that of the conventional vessel. The saving in direct fuel cost resulting from the use of nuclear power is capitalized, and from this is calculated the additional capital expenditure which could be incurred in the reactor and associated equipment of the nuclear ship for it to be commercially competitive with the conventional ship.

Provided the direct fuel cost of nuclear power is low, the additional investment in the nuclear ship which can be justified on economic grounds is substantial, but at present it is not known how far this would cover the costs of reactor plant. For larger tankers than those considered, nuclear propulsion would be economically more attractive, but the scope of their application is smaller. Finally, the authors consider some of the engineering and safety problems connected with marine application. The only power reactor so far developed in this country is the gas-cooled graphite-moderated reactor, and it is considered that, should there be any immediate project for a British nuclear-powered merchant ship, there would be no alternative to this type, probably using enriched fuel in order to reduce size and weight.

Sir Christopher Hinton and Mr. Moore in reference (2), point out that, providing materials of

construction make it possible to build a nuclear reactor which will give a reasonably high temperature in the heat cycle, the weight and size of the reactor will depend on the lattice spacing of the fuel elements in the core and on their specific rating (*i.e.*, the rate at which heat can be extracted from the fuel elements in operation). Obviously, if the specific rating is doubled, twice the amount of heat and, therefore, twice the amount of power can be obtained from a reactor of given size and weight.

For a given specific rating of the fuel elements, the size of the reactor core will depend on the lattice pitch of the fuel elements, which, in turn, is determined by the ratio of moderator to fuel which is needed to slow the neutrons down to thermal velocities. If graphite, heavy water or beryllium are used as moderators, the lattice pitch is likely to be of the order of 6 in. to a foot. Ordinary light hydrogen, although a wasteful moderator in that it absorbs more neutrons unprofitably than others, is more effective in slowing neutrons down, and thus requires a smaller lattice pitch. When using the hydrogen of ordinary water as moderator, a lattice pitch of only an inch or two is needed, so that a very compact core can be built. Water at sufficiently high velocity is also an effective coolant, making high specific rating possible. For these reasons, a reactor using ordinary water as moderator and coolant can be designed to have a low weight per H.P.; but, due to the high absorption capacity of hydrogen for neutrons, fuel costs tend to be very high, because a highly enriched fuel must be used to counteract the neutron wastage due to hydrogen absorption and increased leakage effect of small size.

Such reactors, although attractive for naval use, tend to be uneconomical for merchant-ship use. Furthermore, although water is a good low-temperature coolant, it has severe limitations at high temperature. To achieve an outlet temperature of 550° F, the primary circuit must be pressurized at 1,500 psi, requiring a minimum plate thickness of 6 in. for a pressure vessel of 10 ft. internal diameter, and the need to provide facilities for charging and discharging the closely-pitched fuel rods, presents a severe design problem.

High-temperature water is highly corrosive, and for this reason, plants so far built have been constructed largely of stainless steel. In addition, the present cost in Great Britain of fuel having the necessary high enrichment makes a pressurized-water reactor economically impracticable for British owners. Even with all these disadvantages, however, the pressurized water reactor remains a class of reactor potentially of interest for marine propulsion because of its compact core.

In considering the possibility of the marine application of the gas-cooled, graphite-moderated reactor the specific rating must be considerably increased over that which pertains at Calder Hall. This can be done to a certain extent by keeping the fuel in rod form (which promotes good neutron economy) and providing the cladding material with extended surface. The use of magnesium for this duty was a big advance over the use of aluminum, as not only does it absorb fewer neutrons, thus permitting freer use of extended surfaces, but also, unlike aluminum, it does not react with uranium. Its use has permitted fuel-element temperatures to be raised about 200° F, with consequent improvement of heat-transfer rates. However, to increase fuel rating still further, the uranium must be spread so as to increase the surface-to-volume ratio of the fuel. This can be done only at the expense of slightly enriched fuel. For example, if, by an assembly of small rods or flat plates, the surface-to-volume ratio of a fuel element is increased by a factor of 30, then its specific rating under equivalent conditions will be about five times that of the corresponding single solid rod. It is quite apparent, therefore, that very substantial reductions in weight per H.P. can be achieved in this way; but, before such a technique can be exploited in an actual plant, consideration must be given to the effects of increased rating. The increased neutron flux density, which is a direct result of increased rating, intensifies the irradiation damage in the graphite moderator and in the reactor structural materials; it also intensifies the corrosion effects of the coolant on the moderator.

After mentioning some of the fault conditions to be analyzed, the authors point out that the margin between the operating temperature and the melting point of the cladding material would be very much increased if zirconium (melting point, 3,390° F) were substituted for magnesium (melting point, 1,165° F). The maximum operating temperature of the fuel elements would have to be increased by about 90° F to compensate for the poorer thermal conductivity of zirconium compared with magnesium, and a slight increase in enrichment would also be necessary, because of the former's rather higher affinity for thermal neutrons. Another possibility permitting high specific ratings is to form fuel elements of uranium oxide clad in beryllium (melting point, 2,330° F). Beryllium has a low affinity for neutrons and a high melting point.

Limited but impressive experimental results indicate that a ceramic form of uranium is more irradiation resistant than the metal. The adoption of high-temperature cladding material for such a fuel element would enable considerable increase in the maximum temperature and rating, with consequent reduction in size of heat-exchangers and turbines. Using fuel elements of this sort, the authors consider that it should be possible to achieve ratings which would enable reactors of this type (gas-cooled, graphite-moderated, slightly-enriched fuel) to be installed in large ships.

Considerable further experimental and develop-

ment work is required to perfect fuel elements and to investigate the problems associated with a highly-rated reactor in a ship. Some of the problems are mentioned and dealt with. The feasibility of 50,000 S.H.P. and 25,000 S.H.P. reactor-powered units were investigated and arrangements and proposals are given in reference (2). Making actual comparisons with a conventional ship fueled with oil at 135s. 0d. per ton, it is shown that the cost of transport of oil in a ship of 100,000 tons deadweight, is 6 per cent more than the conventional ship, and about 14 per cent more if the comparison is made for a ship of 45,000 tons deadweight. If oil costs 170s. 0d. per ton, then a nuclear ship of about 70,000 tons deadweight will break even.

In conclusion, the authors consider that there is, as yet, no reactor system which is likely to be economical in ships of 20,000 tons or less (which comprises the largest proportion of ships). Nevertheless, because of the continuing rate of development in the direction of lower weight per H.P., and lower capital and fuel costs, confidence is expressed that such reactors will become available within 10 to 20 years.

The closed-cycle gas turbine, in combination with a gas-cooled reactor, offers not only an efficient, but also a simple, nuclear-power plant, provided a sufficiently high temperature can be provided. In reference (3), the authors have prepared a detailed study of such a combination for a marine power plant of 20,000 S.H.P., suitable for installation in a tanker. The closed-cycle gas turbine is an eminently suitable marine power plant because of its good part-load efficiency. As it is a closed circuit, it avoids the contamination and corrosive problems of the open-cycle gas turbine, but introduces the possibility of contamination by gaseous fission products, if the gas of the closed cycle is used as the reactor coolant, which is the case in this proposal. Decontamination is dealt with later.

A double loop system, using a primary reactor coolant and a heat-exchanger to heat the gas for the turbine system, is not considered desirable, due to reduction in available temperature resulting from the temperature drop across the heat-exchanger. Such loss reduces cycle efficiency and offers increased complexity, weight and maintenance. Using the working fluid as the reactor coolant imposes a further set of conditions on the gas with regard to nuclear characteristics, in addition to those already required to make it suitable for the turbine cycle. Nitrogen was selected as the working fluid for the study. It is chemically inert, relatively inexpensive and readily available, while its density is close to that of air which makes it very suitable for the turbine-compressor circuit. The radiation stability is considered good and, if properly purified, conditioned and replaced periodically, it is believed that the gas can be circulated directly through the reactor and gas turbine without requiring secondary shielding for the turbine-compressor circuit.

The thermal characteristics of nitrogen are such that the head requirements of the power turbine can be met with a single-stage radial inflow wheel. Such a turbine is very attractive for marine use, as the very nature of its design permits it to be used as a direct-reversing turbine. Adjustment of the guide blades permits either ahead or astern operation with the possibility of holding the then existing gas horse-power at zero torque for subsequent use in maneuvering. Helium is a very attractive reactor coolant from the standpoint of its nuclear and heat-transfer characteristics, but it poses considerable problems in machinery design and would not permit the use of a direct-reversing turbine. It is very expensive and the supply is restricted, whereas, when using nitrogen, a small nitrogen-producing plant could even be provided on board ship.

The gas cycle proposed is two-stage compression with inter-cooler from 170 psia, 115° F to 737 psia, 263° F, at which condition it traverses a recuperator and emerges at 727 psia, 773° F. In acting as reactor coolant, there is a condition change to 705 psia at 1,300° F, in which state the gas enters the h.-p. turbine driving the compressors, exhausting into the l.-p. power turbine at 307 psia and 1,008° F. The power turbine exhausts at 178 psia, 830° F; the recuperator reduces the temperature to 324° F, and a final pre-cooler reduces it to 115° F, at which condition, it enters the l.-p. compressor.

The specification of the turbines, compressors, heat-exchangers, gas decontamination system is dealt with in fair detail. It is pointed out that the heat rejected in the pre-cooler could be used for a variety of shipboard purposes.

Because of the restrictions in the United States on the export of fuel elements containing more than 20 per cent of U-235 (the fissionable isotope of uranium), and because a tanker would work in international waters, the authors decided to confine the design of reactor to one using no more than 20 per cent enriched fuel. Furthermore, because of the manufacturing position at present, they decided to use fuel elements containing 30 per cent uranium oxide in a stainless-steel matrix and to use beryllium oxide as moderator. The fuel element is a light hexagonal prism of about 2½ in. across flats; the coolant passes through small circular channels arranged parallel to the axis of the element.

Metal fuel elements were chosen because there is considerably more information available on them than on the ceramic type. However, it is expected that, after further development work is completed, the ceramic fuel elements will prove to be more desirable for reactors using higher temperatures. Moderator blocks of similar shape fill out the spaces between the fuel cells, and the final proposed reactor assembly forms a core approximately 15 per cent

voids, 15 per cent fuel and 70 per cent moderator, which is surrounded by a reflector. Careful attention to gas-flow path results in considerable thermal insulation being provided by the incoming gas, so that the outside shell temperature is estimated to be 150° F; the internal pressure is 727 psia. The neutron and gamma radiation shield is provided by 6 ft. of barytes concrete. The instrumentation and controls proposed are also dealt with.

It is only within the past two or three years that there has been any great interest shown in the United States in the gas-cooled reactor. Reference (4) sets out some of the advantages and disadvantages, with especial mention of the coupling of a gas-cooled reactor by a single loop to a closed-cycle gas turbine, as described previously (reference (3)). In addition to the advantages of simplicity and light weight, already mentioned, there is another important one, *viz.*, containment. Containment usually takes the form of massive steel and concrete walls, which withstand the pressure generated should high-temperature coolant be liberated. Containment of this kind can be very expensive and can form an appreciable fraction of the overall cost. Considerably less energy is stored in a gaseous coolant than in a liquid coolant (especially pressurized water) since it will not undergo a phase change; thus, for the closed-cycle gas-cooled reactor, containment is simpler and cheaper.

There are, of course, several features that require further study and development. The permissible operating temperature is the key to the eventual success or failure of this type of reactor, and the effects of high-temperature operation are felt in many areas. For example, diffusion of fission gases through the metal cladding of fuel elements is known to be very sensitive to temperature, increasing, in some cases, by as much as a factor of 10 with a temperature rise of 200° F. Fission gas diffusion largely determines the extent of coolant activity, which, in turn, dictates shielding considerations, machinery accessibility and coolant leakage consequences. Specific information is required on fission-gas diffusion characteristics at elevated temperatures.

Another problem concerns gas seals on the turbo machinery, and the author points to it as a definite item requiring experimental investigation, because if such seals are unsatsifactory, some secondary form of shielding will be required around the turbines. He also points out that fuel-handling procedures can tie up a considerable amount of capital, if they have to use elaborate, remote fuel-handling equipment, especially in the case of plants where loading and unloading will be carried out relatively infrequently. An approach, usually applied to water-cooled reactors, offers much in the way of simplicity —the reactor and region above it are flooded and most fuel-handling can be conducted directly, using simple, long-handled tools. In the author's opinion, the study stage of the closed-cycle gas-cooled reactor is now complete, and it is shown to be potentially a very attractive source of power. The next stage is to find out how many of the basic problems can be readily solved; if they can be solved, then the closed-cycle gas-cooled reactor will be a very flexible prime mover.

Yet a third type of reactor is considered as possibly being suitable for marine application and is receiving considerable attention, *viz.*, the homogeneous aqueous reactor. The author of reference (5) describes such a plant, which is believed to represent the most economic system practicable for a United States merchant ship to use, in view of the present state of reactor technology in the United States.

The fuel proposed is a dilute solution of uranyl sulphate in heavy water, the uranium being more than 90 per cent pure U-235. The water acts as a moderator and, when the fluid is circulated through a heat-exchanger, as a coolant. A great advantage of any fluid-fuel reactor is its ease and economy in fuel-handling. There need be no provision for depoisoning or gas removal; it could be run for about 20 years without removal of the fuel charge.

The working fluid would be made up regularly with fissile material to replace that consumed. The small amount of used fuel solution to be withdrawn and replaced with fresh solution each year could be handled easily in one day, whereas a considerably longer period is anticipated as being necessary for solid-fuel reactors. No reprocessing of used fuel at all is required.

The economics of such a plant for raising steam in a tanker of 38,000 tons deadweight, requiring 20,000 S.H.P., are discussed and the situation analyzed. The conclusion is reached that, on the run between the Persian Gulf and the Delaware River, the nuclear tanker would show overall costs per cargo ton delivered about 20 to 40 per cent higher than those of a conventional tanker.

The proposed system has two loops (it is not a boiling reactor). Saturated steam is generated in heat-exchangers at 600 psig and is superheated to 865° F in separately-fired superheaters. As was demonstrated some years ago by the homogeneous reactor experiment at Oak Ridge National Laboratory, the aqueous homogeneous reactor requires no control rods of any kind. It is automatically self-regulating, by virtue of the effect which the temperature and density of fuel returning to the reactor have upon neutron criticality. The various protective and safety devices proposed are described.

The author considers that the further development which is required to make this type of reactor truly competitive is to be looked for in the following directions:—

(*a*) Development of an efficient fluid-fuel con-

verter-reactor system instead of a burner-reactor, so that the cost of fuel can be greatly reduced.

(*b*) Development of a system of continuous radioactive decontamination of the fluid-fuel during use, so as to reduce further the hazard from collision, which would cut the cost of the insurance premiums.

(*c*) Development of high-temperature fluid-fuel reactors, so as to increase the thermodynamic efficiency of the plant, with consequent reduction in fuel costs.

Each is further discussed in the paper.

In their paper on "Some Problems in the Application of Nuclear Propulsion to Naval Vessels," reference (6), the authors discuss the extra shielding and safety precautions required. They point out that if the extended endurance which is inherent in nuclear power is to be exploited, the reliability and accessibility of all machinery components must match it. As a result, many components in nuclear plants are larger and heavier than corresponding components in conventional plants. Suitable matching of component characteristics and core in design and arrangement can reduce such increases in weight and space. Several reactor types and cycles are considered, but the authors come back to the pressurized-water reactor (solid fuel), on account of its great advantage that the basic problems, such as coolant technology and component design, have already been solved, and that such reactors have already been constructed. The economic aspect, which almost prohibits consideration of their use in merchant ships, does not, of course, carry the same importance in naval use.

In reference (7), "Materials Problems in Nuclear Reactors," the author discusses general engineering requirements of reactor materials, factors in the selection of reactor materials, components of a nuclear reactor, nuclear fuels, moderators and reflectors, control materials, coolants, shielding materials, structural materials, and solid-fuel elements. In considering the cost of actual fuel burned, it is estimated that the cost of uranium-235 is 15 to 30 dollars per gram, plus the cost of fabricating the fuel plates and assembling them into fuel elements, then, when about 25 per cent of the uranium-235 has fissioned, the fuel element must be replaced. The remaining uranium in the fuel plates must be separated from the fission products, and be recovered for re-use.

To summarize, it appears that there are four main types of reactor likely to be suitable for marine use:—

(1) Pressurized-water reactor with solid fuel; already successfully used for naval vessels; very expensive fuel.

(2) Homogeneous aqueous reactor; being investigated in the United States, for possible use in merchant ships.

(3) Gas-cooled reactors coupled to closed-cycle gas turbines; being investigated in the United States, for possible use in merchant ships.

(4) Gas-cooled, graphite or other moderator, solid-fuel reactor with intermediate heat-exchange; being investigated in Great Britain, for possible use in merchant ships.

Types (1) and (2) use very highly enriched fuel, type (3) uses a fuel of considerable enrichment and type (4) uses only moderately enriched fuel.

Miscellaneous

Welding and Heat-treatment

The British Welding Research Association have published a 28-page handbook concerning the heat-treatment of welded construction in mild-steel and in low-alloy steels. The principal factors governing the choice of heat-treatment for particular types of construction are detailed, and recommendations are made, based on good present-day practice and current code requirements. The information is clearly set out and a most useful glossary of terms used is provided.

In connection with fatigue properties of welds, an article by Mr. J. G. Whitman, in *Sheet Metal Industry* (July, 1957), describes the various factors that are responsible for the reduction of fatigue strength of welded joints, and summarizes the existing information on fatigue behavior of butt and fillet welds in mild steel, explaining the low values which are accepted, such values being especially low for fillet welds. A table is included of comparatively well-established fatigue strengths for mild-steel joints. The fatigue strength of welded high-tensile steels is discussed, but only one actual test result is mentioned, there being little else available. It is concluded that, under fatigue conditions, welded joints in such steels can only be advantageously used for high ratios of dead-to-live load. There is a similar paucity of published fatigue results for welded aluminum alloys, and those that are known, are very low; alloys with higher static strength being no stronger under fatigue conditions of a welded joint than those with a lower ultimate tensile strength. Spot-welding of steel and aluminum is mentioned, and results indicate that fatigue strengths of such welds can be improved by mechanical pressure.

During the past year, tests have been reported on a new type of burner for flame-hardening steels (see the American *Welding Journal* for March, 1957, "Rockets for Steel Hardening," by Mr. James A. Browning). Termed a rocket, it burns oxygen and propane at 100 and 80 psi, respectively, the hot gases issuing out of a slot orifice at 5,400° F and at 4,000 ft. per sec. (about 10 times that of an open oxy-acetylene burner). A sharply-defined narrow band of material, about 1/4 in. wide and 1/16 in.

deep, is heated beyond the transformation point and is then rapidly quenched. A very fine grain structure is produced with high hardness, due to the very rapid rates of heat transfer and the short time permitted above the transformation temperature. The depth of hardness and its degree can be controlled by suitable variation of oxygen-propane ratio, rate of burning, and rate of forward feed. The high feed rates which are possible are expected to result in considerable labor saving, and a big reduction of overall cost per unit area is also expected.

Material Testing and Examination

Report No. P.1 (1957) of the Admiralty Advisory Committee on Structural Steel is in two main parts, *viz.*: — (*a*) a survey of the present state of knowledge of brittle fracture of mild steel and (*b*) a review of research work at present being carried on in the United Kingdom. The survey covers the main aspects of brittle fracture and recognizes that at present no single test is completely satisfactory for assessing the notch ductility of a steel, and that formulation of such a test (or simple series of tests) is of the utmost urgency and importance. Thus, comparative tests are to be carried out by Charpy V-notch, Tipper, Robertson, Van der Veen and wide plate test methods on samples of at least four types of mild steel, as now used in heavy construction, over a range of temperatures. The aim is to draw up an acceptable test procedure, which will provide correlation between test results and service behavior. It is suggested that more laboratory work is needed to explore the way in which manufacturing and metallurgical conditions influence the temperature below which a steel becomes subject to brittle fracture.

Other recommendations include continuance of the long-term studies of micro- and macro-mechanism of brittle fracture, and especially the need for greater understanding of the relationship between energy release and crack propagation in large structures. In this connection, there is, in the *British Welding Journal* of February, 1957, an important report by Mr. A. Almar-Naess on work carried out on tests in which the available external energy is varied by different methods, in order to investigate its influence on the mode of fracture. Specimens were bent with spring loading or in a loading jig, and it is reported that, with such conditions, external energy released from the testing equipment has the same qualitative effect as the release of internal energy. Thus, if the transition temperature of a material, defined by 50 per cent brittle area, is determined by using notched bend specimens, the result is influenced by the testing machine response. A "soft" machine gives a higher transition temperature than a "stiff" one. A similar influence on notched tensile tests is expected. It therefore follows that, if a fracture is initiated in service, its likelihood of going brittle depends on the stiffness of the entire structure, as well as on the static stress distribution in the immediate vicinity. The greater the amount of elastic energy released from the structure by the crack propagation, the greater is the possibility of brittleness.

By means of a special nitrocellulose lacquer, known as Replic, it is now possible to obtain perfect transparent replicas of a metal surface, irrespective of its size or curvature. Such a method is particularly useful for examining inconveniently placed surfaces, which cannot be observed directly and from which samples cannot be cut. Detailed instructions regarding the application of the lacquer, as well as the removal, mounting and examination of the dry Replic, are given in the paper "Non-destructive Method for Macrographic and Micrographic Examination of Metal Surfaces," by M.P.-A. Jacquet and Captain A. van Effenterre, to the Association Technique Maritime et Aéronautique.

If the microstructure is to be examined, the surface being explored must be polished before application of the lacquer. It is suggested that the polishing can be carried out by means of an electrolytic pad, which consists of an electrode surrounded by spongy insulating material saturated with an appropriate electrolyte. This technique facilitates the inspection of metal components already in service, and success has been achieved with many different metals and alloys. In particular, as the lacquer does not become radio-active, it could be of use in the examination of components used in nuclear power plants.

Corrosion

The pitting of tanker plating exposed to crude oil has been investigated by the Research Laboratories of the Hüttenwerke Oberhausen A.G., and experimental work on the effect of tank-cleaning by jets of hot water has also been carried out, in addition to the usual work on the immersion of specimens in crude oil and sea-water, metallographic studies of damaged plates, etc. It was found that Persian crude oil, in association with sea-water, loosens mill-scale; but, even in the presence of considerable oxygen concentration, no dangerous attack occurs with this mechanism only. Furthermore, no significant acceleration of the intensive pitting attack is occasioned by pores in the mill-scale, irregularities of the surface, local activation stimulated by grinding or sand-blasting, or due to variation of chemical analysis within the limits allowed by classification societies. However, it was found that the impact of hot-water jets on the plating initiates attack and intensifies the subsequent pitting. The conclusion is come to that the dangerous form of pitting corrosion in tankers is not purely electro-chemical and that the predominant factor is the association of cavitation, together with normal electro-chemical oxygen

attack. Thus, it is suggested that jet pressure and temperature should be a minimum for tank-cleaning and that nozzles should not be nearer to the plating than 6 ft. 6 in.

In an article appearing in *The Journal of Commerce* (Shipbuilding and Engineering Edition) of the 25th June, 1957, a note is given of yet another multi-fin anode system for cathodic protection of tanker compartments. Anode holders are used, which enable deck-head anodes to be fitted without staging; a simple locking device permits anodes to be easily removed and refitted. Certain of the anodes are of the dual-fin type and provide the necessary high initial boost to establish the protective alkaline film. It is claimed that installation can be carried out at sea as readily as in port and it is recently reported that 10 compartments in the tanker *Gannsfjord* were equipped in 5½ working days between the United Kingdom coast and Port Said. Under average working conditions, anodes will require renewal at approximately three to four yearly intervals.

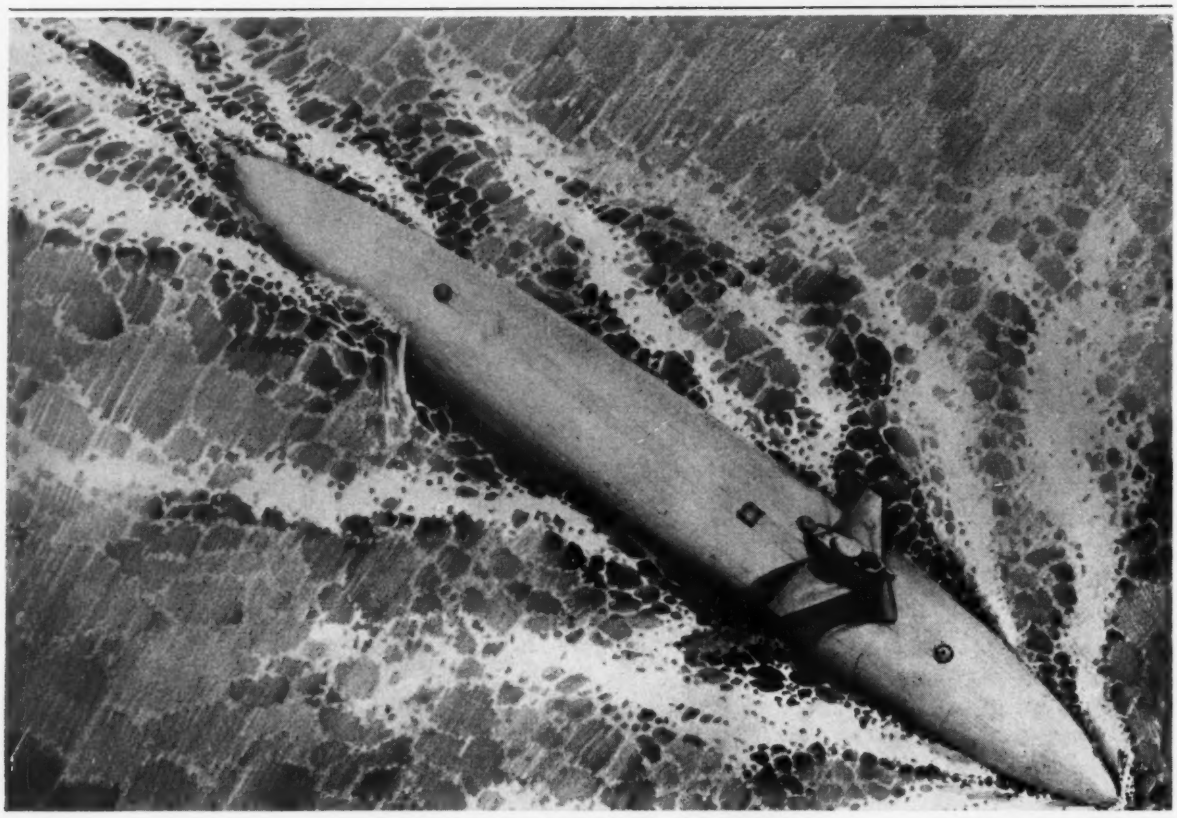
The Shipbuilder and Marine Engine-builder for July, 1957, reported an impressed current cathodic protection system fitted to the ballast tanks of the ore-carrier *Trinculo*. A steam-driven alternator supplies A.C. to transformer rectifiers mounted at convenient points adjacent to the ballast compartments, in which are installed the energized silicon-iron anodes. The system is more flexible in operation than the ordinary magnesium anode systems, and thus a heavier calcareous film can be deposited to protect the tanks from atmospheric corrosion after ballasting.

Zinc anodes containing more than 0.0014 per cent iron have been found to lose, very rapidly, their effectiveness for protecting the steel hulls of vessels fitted with bronze propellers. A new United States military specification has been issued, limiting the permissible iron content to this figure. The Boston Naval Shipyard conducted a service test of anodes to the new specification, and a harbor tug of about 2,500 sq. ft. of wetted surface was fitted with 30 anodes, 15 on each side, after being painted with a standard hot plastic paint. After 17 months of service, the tug was dry-docked, and it was found that excellent protection of the paint had been provided by the electrodes. Of the original 690 lb. of zinc, 135 lb. were consumed, and, calculated from this figure, the average current density needed to protect the hull was 1.1 milli amp. per sq. ft. of hull surface. The vessel was returned to service without repainting or changing the anodes, and it is estimated that the combination of paint and high purity anodes will remain effective for four or five years.

In Germany, good results have been obtained with hull-protection systems consisting of a zinc layer sprayed on a rust and dust-free surface, followed by paint layers. Given the correct preparation and an annual wash and touch-up, the life of such a system is estimated at 10 years. The first costs of hull-protection systems consisting of (*a*) paints applied over rusty surfaces, (*b*) paints applied over flame-cleaned or sand-blasted surfaces, and (*c*) zinc layer applied over surfaces prepared as (*b*), followed by paints, are estimated to be in the ratio of 1: 2: 3; but it is claimed that the higher first cost of the zinc system is compensated for by longer life, lower maintenance costs and shorter docking periods.

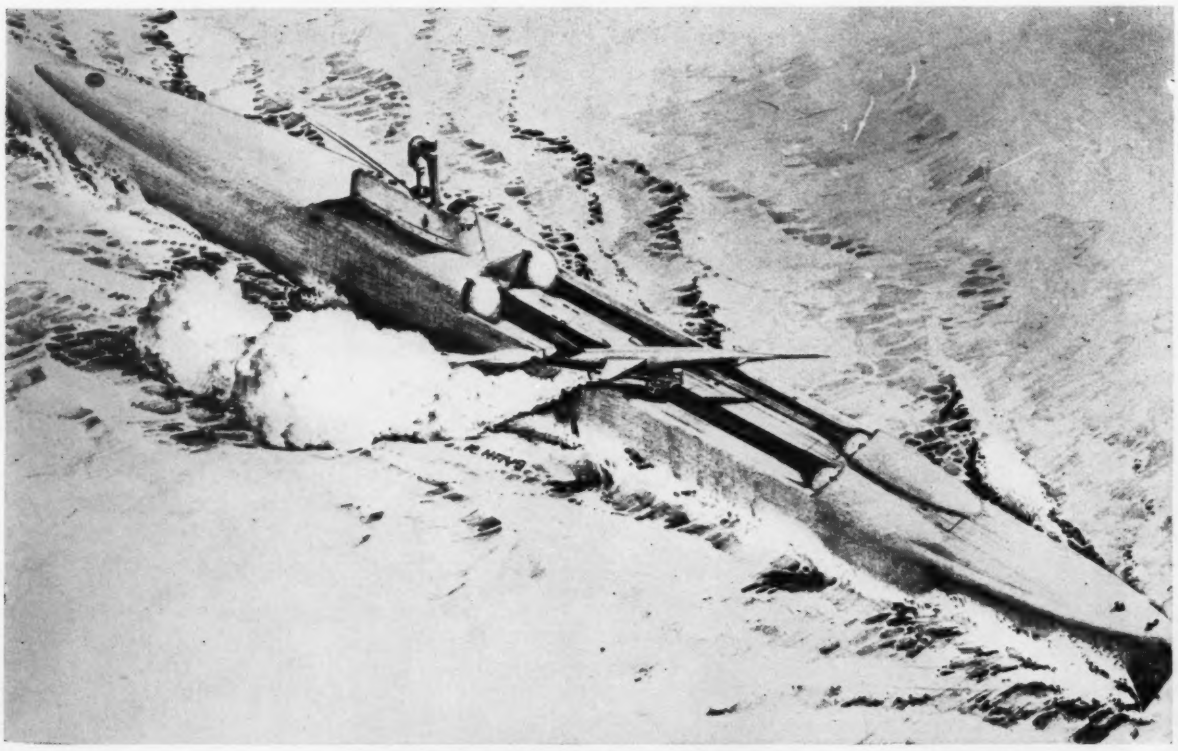
Gas turbines have been installed as the main propulsion power for patrol craft being built for the British Navy. Three turbines, having a maximum continuous rating of 2800 HP each will drive the three-screw installation. The weight of the installation, including the reduction gears, is about 1.6 lb. per HP. The craft has a length of 98 feet and a beam of about 25 feet. Smaller auxiliary gas turbines provide electrical power for the patrol craft.

—from "Mechanical Engineering," March, 1958



SS(N)—NUCLEAR POWERED SUBMARINE *Official U. S. Navy Photograph*

This new design, the first of its kind, will greaty enhance our anti-submarine forces. Designed for optimum sonar and submarine attack features, it can conduct ASW operations from areas not accessible to surface ships.



SSG(N)—GUIDED MISSILE SUBMARINE *Official U. S. Navy Photograph*

The combination of nuclear propulsion and long-range missiles with powerful warheads makes this submarine a potent addition to our fleet. This design is also capable of operating against enemy surface ships or submarines.

FRANK E. CLARKE

A QUARTER CENTURY OF COOLING WATER TREATMENT FOR NAVAL DIESEL ENGINES

THE AUTHOR

graduated from Western Maryland College in 1935 with degrees in chemistry and education. Studied advanced physical chemistry for one year at University of Maryland and taught chemistry for five years before entering the EES Chemical Laboratory in 1941. He became Head of the Boiler Water Section in 1942, Head of the Chemical and Physical Branch in 1946 and Head of the Process Branch, Chemical Engineering Laboratory, in 1951. He has been in charge of EES development work on Diesel engine cooling water treatment since 1942.

THE FIRST EXPERIMENTAL diesel engine had no cooling water problems because it had no water jacket. However, it had cooling problems which led to incorporation of a cooling water system in the second model shown in Figure 1. Over the years, the cooling water system has proved to be an essential, though somewhat troublesome, part of the engine.

As improvement in engine design gradually minimized mechanical troubles and combustion problems, cooling water problems became relatively more prominent until they finally constituted a separate important field of development. The Navy has played an important part in this development, particularly in the field of marine diesel operation. Its work during the past quarter century has been an interesting program of discovery and rediscovery, of useful cooling water treatments for ever changing engine designs. It would be incorrect to say that this research has eliminated all problems, just as it would be incorrect to say that medicine has eliminated all human ills. On the other hand, the present freedom from general serious waterside problems is evidence that the treatments developed by the program have been adequate if not perfect answers to Naval needs.

THE CLOSED COOLING CYCLE

It is not surprising that early land based diesel engines had open (once through) cooling systems. This was the simplest and most economical engine design. While the fresh waters used in cooling such engines undoubtedly varied considerably in composition, they probably were relatively low in solid content, particularly suspended matter and sediment.

The first marine diesel engine (Figure 2), installed on a French canal boat in 1902, presented new cooling water problems. Mud introduced with the cooling water seriously sludged the heat transfer surfaces and led to engine overheat. Later marine diesels also were troubled by relatively high salinities and mineral hardness contents of brackish water and sea water which increased the probability of corrosion and scale formation on their waterside. These problems were not completely intolerable, witness the fact that some marine diesels still use open cooling water systems and water of relatively poor quality. However, they were troublesome enough to result in development of the closed cooling system with primary fresh water cooling for engine heat exchange surfaces and secondary sea water cooling for the engine jacket water. In 1925, an ASNE note estimated that about one-half of the marine diesels used straight sea water cooling while the other half used fresh water cooling or some combination of the two. Preferences apparently varied with manufacturers, some using sea water for cylinder cooling and fresh water for piston cooling, while others used the opposite. As late as 1933 when the Engineering Experiment Station started

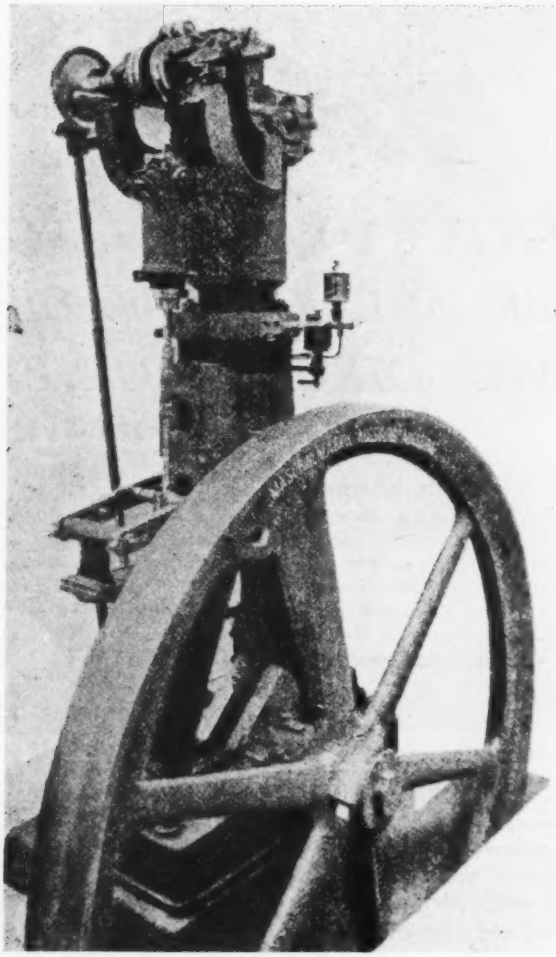


Figure 1. First Diesel Engine with Water Cooling.

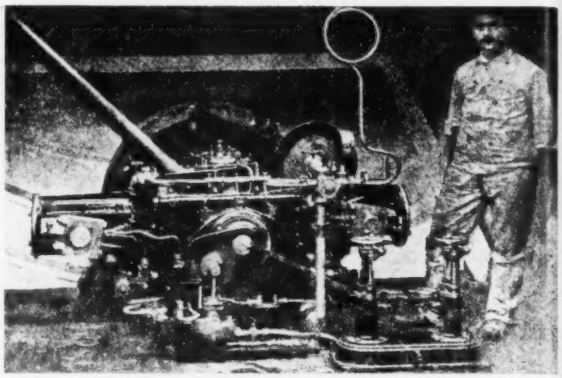


Figure 2. First Marine Diesel—Open Water Cooling (1902).

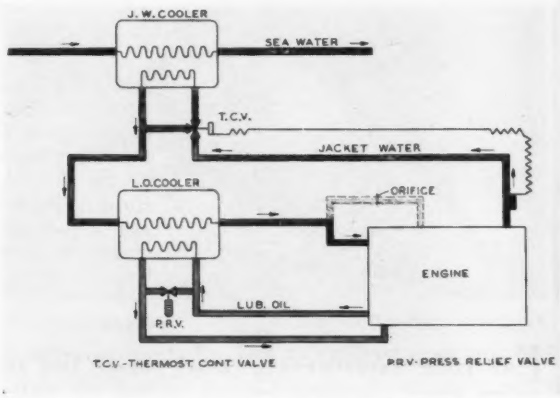


Figure 3. Modern Closed Cooling Water System (Submarine engine).

intensive work on engine coolants, open sea water systems still were very common in the Fleet.

The first closed cooling system consisted simply of a pump and piping for circulating fresh water through the engine channels and then through an external cooling coil in an open sea-water tank serviced by a second pump. Eventually this developed into the present type of closed marine engine cooling circuit with its lubricant coolers, pressure regulators, and temperature controls. The cooling system illustrated in Figure 3 is a common one in the present submarine Fleet, but it is by no means the only effective arrangement. Primary coolant (fresh water) flows through the engine jacket and temperature regulator to a sea water heat exchanger called the jacket water cooler. From here it flows through the lube oil cooler back to the engine block. Thus, sea water cools the jacket water which cools the lubricating oil and the engine. The sea water circuit is an open (once through) system, whereas the jacket water flows in a closed system. Only the latter requires treatment. A typical temperature profile is shown in Table I.

The cylinder sections in Figure 4 show how the jacket water cools the cylinder liner and exhaust manifolds of a Navy opposed piston diesel. The interior of a typical strut-type sea water heat exchanger is shown in Figure 5. The heat exchanger cooling element, also shown in this figure, consists of male and female sections of dimpled metal copper-brazed to form a flattened tube through which the jacket water flows.

A typical modern marine cooling system contains a great variety of metallic and non-metallic components which vary somewhat from ship to ship. The jacket water surge tank and piping may be galvanized steel, copper, or even copper-nickel. The cylinder liners generally are cast iron or chromium plated steel and the jacket generally is cast iron. Special coatings for metal parts may be used in certain engines.

The struts of the conventional Naval heat exchanger are made of 70-30 or 90-10 copper nickel alloy, since their exteriors are exposed to sea water. However, they are soft-soldered to cast bronze exchanger shells. Fittings in the jacket water system

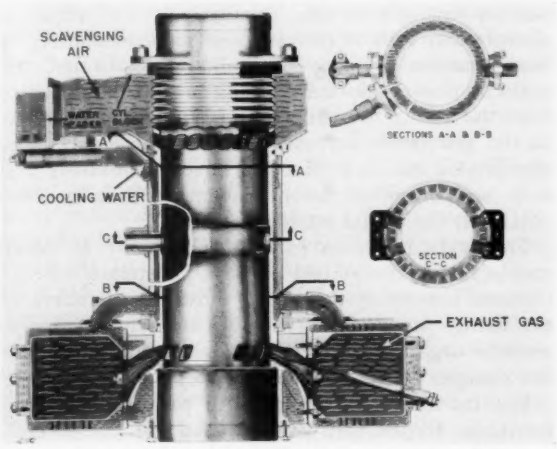


Figure 4. Cylinder Section, Opposed Piston Diesel.

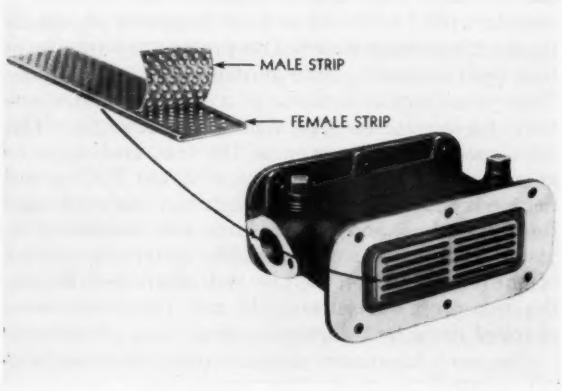


Figure 5. Heat Exchanger, Submarine Diesel Cooling System.

may be brass, bronze, copper-nickel, or monel. Connecting hose generally is Buna N or neoprene synthetic rubber, although natural rubber has been used.

When one considers all of the special installations and material variations resulting from emergency repairs, it is safe to conclude that Naval diesel water treatment must protect almost any common piping or engine alloy.

The closed cooling system and the use of fresh water in the engine jacket did not create the need for cooling water treatment, since obviously this plan would be less destructive than the open cooling system which it supplemented. In fact, closed cooling water systems were in common use at least a decade before any universal systematic cooling water treatment was adopted by the Navy or other marine services. The closed cooling circuit eventually led to systematic cooling water treatment simply because it made such treatment practicable. Cost alone tends to defeat any attempt at treatment of once through cooling systems, particularly when sea water is the coolant. Practically all of the Navy's coolant studies have been concentrated on closed cooling systems and most of the preventive treatments described below fall into this category.

TABLE I—*Typical Engine Cooling System Temperatures °F*

Engine Exhaust	550 to 650
Lube oil from Engine	170 (140 to 180)
Lube oil from Cooler	130 to 150
Jacket water to Heat Exchanger	160 (140 to 170)
Jacket water from Heat Exchanger	110 to 130
Jacket water to Engine	145 to 155
Sea water to Pump	85 (max.)
ΔT Sea water	15

PIONEER COOLING SYSTEM STUDIES

The Navy's first attempts at cooling system care started with a pound of cure rather than an ounce of prevention and were directed at open rather than closed cooling systems. In 1933 the Commanding Officer of the USS *Milwaukee* reported to the Bureau of Engineering (now the Bureau of Ships) that a proprietary cleaner had been used successfully in cleaning scale and corrosion products from the open cooling water channels of a Navy Type BA whale boat engine. Following this report, the Bureau of Engineering authorized the Station in the same year to test several commercial products for "combating excessive corrosion" noted in water jackets of diesel engines. Two of these were claimed to be both cleaners and corrosion inhibitors while the others were marketed as cleaners only. According to the manufacturers' claims, one of the dual personalities was converted from water treatment chemical to chemical cleaner simply by doubling the quantity of material used. Typical compositions, as reported by the manufacturers or discovered in the laboratory, are shown in Table II.

The Engineering Experiment Station's report in November 1933 (Test 6164) eliminated the two dual purpose products, Cleaners C and D, on the basis of calculations which showed that one would cost 12 cents per thousand gallons of cooling water while the other would cost the enormous price of $42.20 per thousand gallons. Both figures were far out of reason for treatment of the open cooling water systems in question. The marked difference in cost between these two products, despite the absence of particularly expensive chemicals in either, shows the extent to which cooling water treatment markets were being exploited during the early days.

TABLE II—*Compositions of Early Cooling Sytem Treatments*

Component	Percent Cleaner A	Cleaner B	Cleaner C*	Treatment
Muriatic Acid, HCl	17	18	15-17	....
Organic Acid	....	....	.....	5
Tannin	1	....	.....	....
Vegetable Extract	1	....	.....	....
Inert	81	....	.....	....

*Contained unspecified amounts of various salts and oxides.

Similar evaluation of the single purpose proprietary cleaning agents in 1934 showed that one was an excellent cleaner, removing water-formed deposits with virtually no attack on the underlying metal, while the others, including the one used on the USS *Milwaukee,* removed as much metal as deposit.

This early investigation did not disclose a suitable standard treatment for cooling water systems of the Fleet, but it did result in approval of one proprietary cleaner for reconditioning seawater-sides of submarine engines. It also made the Navy more conscious of the problem and set the Experiment Station to work on non-proprietary treatments. The first fruit of this work was a non-proprietary hydrochloric acid cleaning procedure for cast iron engine cooling systems. This included neutralization with trisodium phosphate or Navy boiler compound 1933. The latter was a brand new product and the result of extensive Naval research in boiler feedwater treatment during the period 1931 to 1933. The merit of the cleaning method was confirmed by a service test on the USS *Narwhal* of Submarine Division 12 in May 1934. However, the Station's records do not show that it was adopted as a routine waterside cleaning procedure for the submarine fleet.

T. S. P.—FIRST APPROVED COOLING WATER TREATMENT

The waterside fouling and corrosion problems mentioned above in connection with open cooling systems also applied in a lesser degree to closed cooling systems then used by the Fleet. While treatment of the former presented almost insurmountable problems, the closed cooling system was viewed in a more optimistic light. The Experiment Station recommended to the Bureau of Engineering in September 1935 that a program be authorized for developing a non-proprietary cooling water treatment and mentioned sodium phosphates as promising chemicals. The test authorization issued in October of the same year requested inclusion in the investigation of a highly publicized proprietary treatment.

The composition of the proprietary product was secret, as usual, and its composition was not investigated. On the other hand, the sodium phosphates recommended by the Station were well known chemicals which already had been tested extensively for boiler water treatment. The most alkaline member of the family, trisodium phosphate (Na_3PO_4) was an ingredient of the Navy's first official boiler compound (1913). Disodium phosphate (Na_2HPO_4), with its higher ratio of phosphate to alkali, replaced the trisodium salt in 1920 boiler compound and since 1933 has been the principal ingredient of all Navy boiler compounds and boiler water treating chemicals. A third member of the family, mono-sodium phosphate (NaH_2PO_4), provides a still higher ratio of phosphate to alkali.

All sodium phosphates have the ability to convert scale forming ions, such as the calcium and magnesium ions of seawater, to relatively non adherent sludges and thus to prevent salt scale formation on heat transfer surfaces. The alkaline varieties, trisodium phosphate and disodium phosphate, also have the ability to maintain the pH of water systems in the minimum corrosion range (for steel). The phosphates also are effective anodic inhibitors and form temporary corrosion preventive films by reaction with the metal surface.

The wide range in ratio of phosphate to alkali makes it easy to control pH and phosphate concentrations separately by using different members of the family independently. It is common practice to include organic matter such as starch, to fluidize the sludges which result from phosphate treatment.

For its first comparison with proprietary treatment, the Experiment Station used two compounds, a 4 to 1 mixture of disodium phosphate and starch and a 10 to 1 mixture of trisodium phosphate and starch. These were added separately as required to maintain pH 8 to 10 and at least 10 ppm of phosphate ion in the cooling water. The proprietary treatment was used according to manufacturers' instructions. The comparison was made in a single cylinder section of a submarine type Winton diesel engine. This developed 75 horsepower at 750 rpm and operated at a cooling water temperature of 140°F. The test engine is shown in Figure 6. Each test was continued for thirty days and performance was evaluated by visual examination of accessible waterside surface of the engine jacket before and after test. During the non-proprietary test, pH and phosphate were checked daily by colorimetric analytical procedures.

This early treatment study favored the phosphate-pH control method. The proprietary treatment yielded deposits up to 0.25 inch thick and caused temperature and pressure increases above normal of 3.4°F and 1.5 pounds per square inch, respectively, according to the Station's report in 1937 (Test 7558). On the other hand, the non-proprietary treatment which followed left the waterside clean except for a very thin layer of sludge and tended to restore normal temperature and pressure readings. Unfortunately no corrosion test specimens were included in the engine cooling system during these tests and no analytical data were collected on the composition of the deposits.

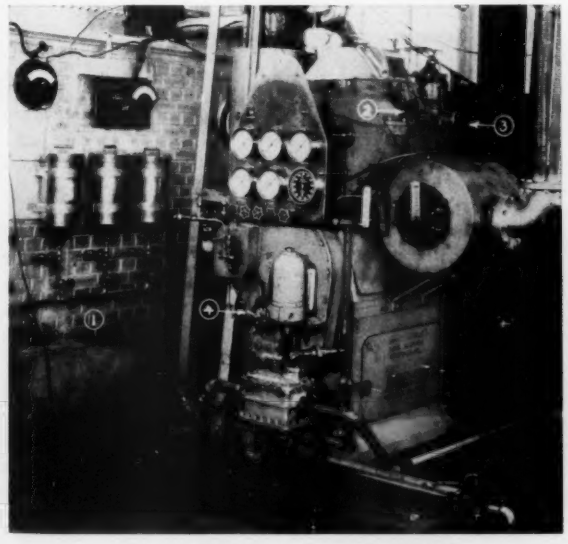
In May 1937, the Experiment Station concluded from the above tests, that control of pH alone would be adequate and that treatment with a 10 to 1 mixture of trisodium phosphate (TSP) and cornstarch, as necessary to maintain pH 8.0 to 10.5 would be suitable for closed cooling systems of Naval diesels. However, it was recommended that the treatment be withheld pending development of a suitable pH control test. Because of this delay, the trisodium phosphate treatment was not the first actually adopted by the Fleet, but it was the first non-proprietary treatment tested and approved by the Experiment Station for closed cooling systems.

Work on the control test for the above trisodium phosphate-starch treatment was started immediately and a special tricolor indicator consisting of a mixture of phenolsulfonphthalein and thymolphthalein in water solution was developed by the Station and recommended to the Bureau of Engineering by an official report in January 1938 (7558-C). When added to a sample of alkaline cooling water, this novel indicator yielded yellow color below pH 8, red color between pH 8 and pH 10, and purple color above pH 10. A bottle of this indicator as it later appeared in the stock system is shown in Figure 7. It proved to be reasonably successful, but the telltale colors were slightly different by reflected and transmitted light. For example, the color representing high pH sometimes was green instead of purple, depending on the test container and the angle of view.

SOLUBLE OIL STOLE THE SHOW

Before the Station had completed its work on the above corrosion control indicator for use with the trisodium phosphate treatment, the automotive and industrial diesel industries were testing, using, and advocating a product called "soluble oil" for protection of watersides of closed cooling systems. The term soluble oil is a misnomer, as the materials covered by this title are neither strictly oils nor water soluble materials. They generally consist of sulfonated petroleum oils containing small amounts of soap or other emulsifiers.

Soluble oils, also known as cutting oils to the machinist trade, vary in color from yellow to dark brown and yield a great variety of odors, depending on the additives they contain. When added to water,



Fiure 6. Winton Test Engine (1935).
1. Fuel System.
2. Oscillograph Terminal.
3. Ignition Indicator.
4. Oscillograph Operation Equipment.

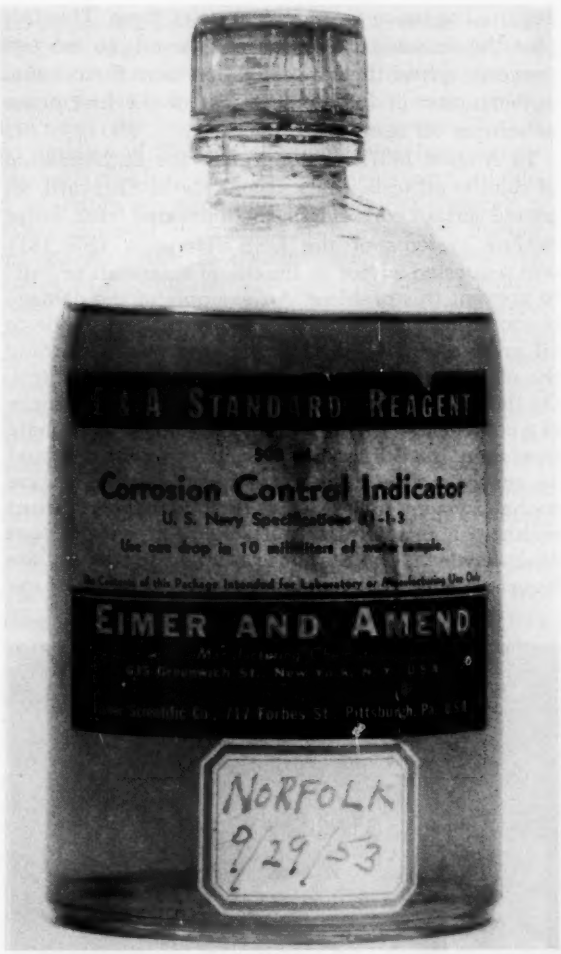


Figure 7. Corrosion Control Indicator (Developed 1938).

all produce a characteristic milk white emulsion, but the resulting pH for a given concentration may vary from 7 to 11.

The ability of soluble oil to protect steel was not understood when it was first recommended as a cooling water treatment and it still is not fully understood. The protective mechanism may involve production of a film on the metal surface, possibly through adsorption of strongly polar components. Some feel that these components may actually react with the metal to form protective compounds.

In May 1937, a week before the Station's report recommended phosphate treatment, the Bureau of Engineering authorized tests of soluble oil products from four major petroleum refiners. These tests were made in the same Winton engine used in earlier studies (Figure 6), except that corrosion test specimens were suspended in the cooling system for a more accurate evaluation of results. The soluble oils proved to be so efficient in preventing corrosion and deposition that periods of at least 600 hours were

required to make any comparison of them. This fact plus the occasional addition of new oils to the test program spread their investigation from the original authorization in 1937 to the close of the first phase of soluble oil testing in May 1942.

In August 1937, not long after the authorization of soluble oil tests, Mare Island Naval Shipyard reported serious corrosion in the untreated fresh water cooling systems of the USS *Pompano* (SS 181) and requested advice on the use of chemicals or "oil" to prevent this problem. An example of the damage is shown in Figure 8. Presumably this reference to oil grew out of local commercial reports regarding the effectiveness of soluble oil for corrosion control. On the basis of exploratory work, and in the absence of a control test for the recently developed phosphate treatment, the Station reported that soluble oil would be an acceptable interim treatment for the engine cooling systems of the USS *Pompano*. The Bureau withheld approval of soluble oil treatments at that time; however, the Station continued to accumulate favorable data on this new product. A report in June 1938 (9105A) showed all soluble oils thus far tested to be markedly superior to the trisodium phosphate treatment as shown in Table III. Following this report, the Bureau issued tentative approval to the submarine force for use of proprietary soluble oils (1% concentration).

Figue 8. Corosion, Untreated Cooling System, USS *Pompano* (SS-181)—1937.

TABLE III—*Performance of Soluble Oil, 1938*

Treatment	Average Weight Loss, g. (30 g. Steel Specimens)
None (Distillate)	0.9510
pH-PO_4	0.5265
Soluble Oil A	0.0506
Soluble Oil B-1	0.0191
Soluble Oil B-2	0.0066
Soluble Oil C	0.0286
Soluble Oil D	0.0107

Long-term full-scale engine tests in the Station's Internal Combustion Engine Laboratory demonstrated conclusively that soluble oil treatment would eliminate waterside fouling and attendant cylinder cracking, then relatively common. The official report of that study, B1690-F(1), was issued in February 1940. Figure 9 from the above report shows cracks which occurred in a cast iron cylinder of a two cycle, Model 201A, submarine type diesel engine during 3629 hours of normal operation with untreated fresh water cooling. Certain of these cracks were found during inspection after only 1980 hours and valve sticking problems were frequent after 1650 hours. Figure 10 shows the heavy waterside deposition and water channel stoppage which led to these overheat problems. Figure 11 shows the same head after 3178 hours of operation on fresh water treated with a soluble oil then under investigation at the Experi-

Figue 9. Cracked Cooling System, Model 201A Submarine Diesel (1940).
1, 2, 3 Indicate Cracks.

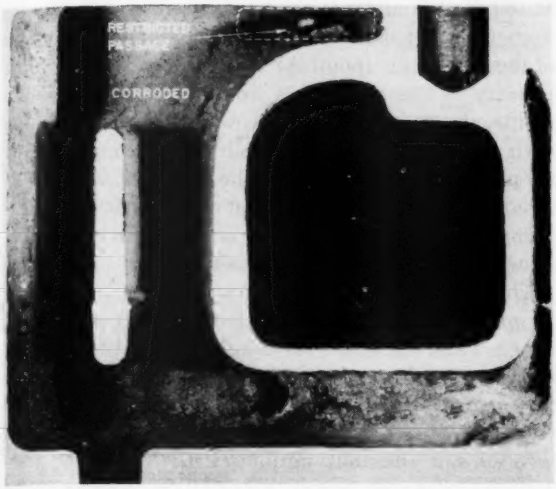


Figure 10. Waterside Deposit, Model 201A Diesel (Figure 9).

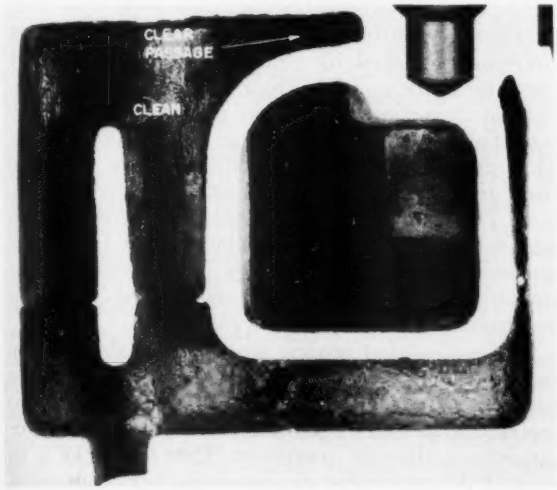


Figure 11. Clean Waterside, Model 201A Diesel After Soluble Oil Treatment.

ment Station. The passages in this case were clean except for a thin oil film and there was no evidence of overheat, increase in circulation pressure, nor cylinder cracking. It also is interesting to note that after eleven months of idle storage, this head still was in the same condition with no evidence of corrosion on the waterside. Needless to say, this led to endorsement of the Station's earlier recommendation for general use of soluble oil in the Fleet and resulted in shelving the TSP treatment approved earlier.

UPS AND DOWNS OF SOLUBLE OIL

The glory of soluble oil was short lived. Before the Station's experimental engine tests of all soluble oils could be completed, serious corrosion occurred on the lower cylinder jackets of engines in the USS *Saury*, despite treatment of their cooling water with approved soluble oil. Since the cause of this serious damage could not be fixed immediately, the Bureau of Engineering abandoned soluble oil in February 1941 and switched to the TSP-starch treatment originally approved by the Experiment Station and detailed in Bulletin of Engineering Information Number 108 (July 1938). Experiments with soluble oil inhibitors were continued despite this change.

This apparent contradiction of laboratory finding was clarified the following year during further studies of soluble oils. Samples of the cadmium plated waterside surfaces of the USS *Saury* were used in Station tests and were found to pit severely on the cadmium plated sides, even though the unplated sides and clean metal specimens were not affected by the same soluble oil solution. This indicated that electrolytic attack due to flaws in the cadmium coatings was the source of accelerated attack in the *Saury* engines and that the treatment really was not at fault. The report of this finding (9105-F of 11 February 1942) prompted the Bureau of Ship's Research and Standards Group (336) to look again at the data collected on soluble oils and other cooling water treatments. As a result of this review, soluble oil treatment again was recommended to the Internal Combustion Engine Maintenance Group (6431) as preferable to all others and the Station was advised in December of 1943 to discontinue all work on other cooling water inhibitors because of the apparent superiority of soluble oil. Thus in the span of four years, soluble oil traveled from the top to the bottom and back to the top of the list of cooling water treatments.

EVOLUTION OF ALKALINE CHROMATE TREATMENT

This treatment entered the picture quietly in December 1938 soon after the Station's first reasonably comprehensive and highly favorable report on soluble oil inhibitors. Its trial was requested by a chromate manufacturer who recommended 200 ppm of chromate ion (as sodium chromate) and pH 8 for preventing waterside corrosion. During the period 1938 to 1943 tests of chromate paralleled those of soluble oils and numerous proprietary treatments. However the performance of chromate was not considered spectacular in view of the phenomenal corrosion prevention properties of soluble oils.

Sodium (and potassium) chromates are yellow, orange, or red crystalline compounds and are anodic inhibitors. In the last respect they resemble sodium phosphates. The protective mechanism of chromate ion, as accepted by most authorities, is reaction with soluble iron compounds (ionic iron) in immediate contact with the iron or steel surface to form a mixture of hydrated ferric and chromic oxides. These cover the surface with a corrosion resisting film and may even penetrate the metal for an appreciable depth.

If added in insufficient quantity, chromate, like all anodic inhibitors may reduce the area affected by

corrosion without actually reducing metal loss. This can lead to accelerated localized attack, particularly in crevice areas, sharp corners and sludge pockets. In other words a deficient chromate treatment may be worse than no treatment at all. For the same reason, chromate protection requires that sufficient chromate ion always be available to repair the oxide film in case of damage. The chemical has very little lasting effect if treatment is discontinued.

In early applications alkali chromate (or dichromate) and sodium carbonate (or sodium phosphate) generally were added separately to provide a so-called alkaline chromate treatment. The Navy's first alkaline chromate tests were made in a Cooper-Bessemer 150 horse-power diesel and were evaluated with metal test specimens pinned to the inside cover of a box inserted in the cooling water circulation line. The chromate concentration was maintained at approximately 50 ppm of chromate ion by adding potassium dichromate and the pH was adjusted to approximately 8 by adding trisodium phosphate. Station fresh water with relatively low solid content was used in this study.

Since the thirty days of engine testing developed very little corrosion on the test specimens, this method was abandoned in favor of tests in the simulated cooling system shown in Figure 12. This was designed and built specifically for coolant inhibitor studies. It was arranged to maintain the temperature at 160°F with internal electric heaters and to expose numerous test specimens to both the quiescent water of the main tank (point A) and to the relatively high velocity of the circulation line (point B). At both points, the specimens were contained in steel boxes with removable covers to which the specimens could be pinned. The volume of the main tank, size of circulation line, and circulation characteristics of the pump were made to simulate existing engine conditions as closely as was practicable.

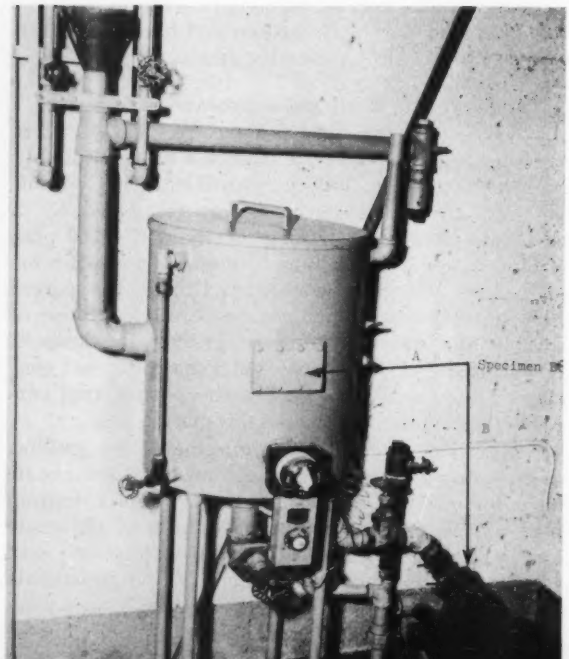


Figure 12. Simulated Cooling System.

These tank tests were made with water containing 50 epm (1773 ppm) of chloride ion added as Severn River water in order to accelerate corrosion rate and shorten the test period. This was far more than the quantity expected in engine cooling systems (normally below 100 ppm) so that the condition favored salt resistant inhibitors. Chromate is particularly superior in this respect and testing it in this manner did not handicap it.

The specimens used (steel) in the tank tests were prepared by surface grinding. Following exposure, they were cleaned by boiling in a solution of lye containing zinc powder. Their metal losses were calculated in inches penetration per year by calculations from total weight loss and total exposed area. This measurement did not differentiate localized from general attack and local attack was very common. The relative protection obtained by chromates was determined by making similar tank tests with untreated water as well as with numerous other treatments. Figure 13 shows one of the specimen box covers with specimens in place.

These simulated cooling system tests showed the recommended 200 ppm of alkaline chromate to be superior to trisodium phosphate treatment and to certain proprietary treatments, but markedly inferior to soluble oil treatment. (See Table IV.) In view of this somewhat disappointing performance of low concentration chromate, the increasing reports of trouble in cooling systems of the Fleet, and the abandonment of soluble oil, the Bureau requested in November 1943 that the Station investigate the higher concentration of chromate and the higher pH range then being recommended by the chromate manufacturer (1 pound of potassium dichromate to 250 gallons of water at pH 8 to 10). This authorization had scarcely been issued when the aforementioned decision was reached to abandon all inhibitors in favor of a return to soluble oil. Consequently chromate studies were suspended temporarily.

Figure 13. Specimen Box Cover with Exposed Specimens.

TABLE IV—*Comparison of Treatments 1942*

Treatment	Average Penetration, IPY (Steel)
pH-PO_4 (TSP-Starch)	0.0121
Proprietary Compound A (Soluble oil)	0.00013
Proprietary Compound B (Chromate)	0.0138
Proprietary Compound C (Chromate)	0.0411
Proprietary Compound D (unidentified)	0.0228
Soluble oil 1	0.000029
Soluble oil 2	0.000025

SOLUBLE OIL SUCCUMBS TO ALKALINE CHROMATE

After its revival, soluble oil treatment apparently remained in Fleet use from 1943 until about 1946 when it again lost favor either because of problems reported by the Fleet or fear of problems reported by industrial users. Experiment Station records do not contain reports of deficiencies, but it is known that certain industries had complained about oil fouling and possible overheat as a result of excessive oil additions.

By this time it was evident that alkaline chromate treatment, though inferior to soluble oil as a corrosion preventive, was markedly superior to trisodium phosphate treatment. Consequently this treatment was substituted for soluble oil, using the highest concentration and pH values then recommended by the chromate manufacturer. The instructions, as first issued in Chapter 41 of the Bureau of Ships Manual, prescribed a chromate ion concentration range of 600 to 800 ppm (900 to 1100 ppm of sodium chromate) and pH of 8 to 10. No special test kit was provided for control of this treatment. The old corrosion control indicator (Figure 7) was found to be adequate for pH control despite the yellow chromate color. The chromate ion concentration was determined by titration with sodium thiosulfate solution in the presence of potassium iodine and starch. Chloride ion, by this time recognized to be an important factor in marine engine corrosion, was determined by the Mohr titration (silver nitrate-chromate) and was kept below 100 ppm by replacing the water in case of contamination. Not all ships were equipped for making these tests. Incidentally, the alkalinity required for pH control was obtained by addition of Navy Boiler Compound (sodium carbonate, sodium phosphate and starch) instead of trisodium phosphate.

While it was recognized that corrosion losses with this treatment were from 25 to 200 times as great as with the best soluble oils, the treatment was considered adequate for extending cooling system life to the expected life of the engine proper.

Alkaline chromate has remained the Navy's standard cooling water treatment for iron diesel engines from its adoption to the present time. However a few years ago, the chromate ion concentration was increased to the range of 700-1700 ppm and trisodium phosphate and lye now are being considered for use as alkalizing agents instead of Navy Boiler Compound.

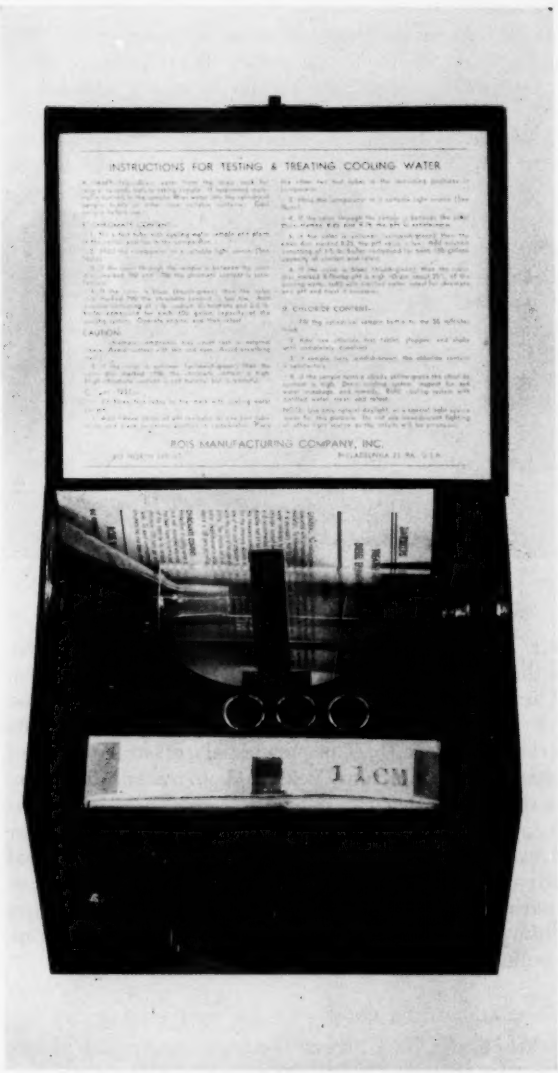


Figure 14. Cooling Water Test Kit for Chromate (1951).

In 1951 the Navy developed its first real engine cooling water test kit for use in conjunction with the chromate treatment (Figures 14 and 15). This incorporates the best features of several proprietary test kits marketed for the same use. It has a disc type color comparator with separate sets of discs for pH and chromate colors and a pill type test for chloride. The chromate color is read directly on the water sample, while the pH color is developed with a liquid pH indicator before comparison with the standards. A dissolved silver nitate pill turns the water sample red with silver chromate if the chloride concentration is below 100 ppm. The water remains yellow with chromate ion if the chloride concentration is above that range.

Both the chromate treatment and its related test

Figure 15. Contents of Cooling Water Test Kit.

kit have proved adequate for the intended use, although the kit has not yet been widely distributed. The same satisfactory performance has been reported by industrial users of similar methods and tests (railways, etc.). The principal disadvantage of chromate, aside from its limited corrosion inhibition, is the fact that it can cause skin irritation in certain hypersensitive individuals, a problem which never occurs if careful handling is exercised. Its principal advantage over other marine treatments is its remarkable performance in the presence of sodium chloride, a common contaminant in diesel engine cooling systems of the Fleet.

ALUMINUM ENGINE BRINGS NEW PROBLEMS

When the Navy turned to aluminum engine blocks for non-magnetic applications, as in mine sweepers, aluminum suppliers recommended against the standard alkaline chromate treatment because of possible detrimental effects of alkali on aluminum parts. The special treatment recommended in its stead was designed to maintain in the cooling water, 1000 ppm of nitrite ion (NO_2), 500 ppm of nitrate ion (NO_3) and smaller quantities of NaH_2PO_4 and Na_2HPO_4. The solution was intended to have a pH of about 8. This complex treatment apparently was intended to provide a many edged weapon. Both phosphates and sodium nitrate are recognized anodic inhibitors which form protective films. In addition nitrate is a pacifier which tends to change galvanic potential and thus to render the metal more noble. Nitrate has been used as an embrittlement inhibitor in iron systems. The phosphates are common constituents of pH stabilizing chemicals (buffers) and also prevent scale by precipitating calcium and magnesium as sludges.

The Navy originally intended to operate its aluminum diesels according to this recommendation. The Experiment Station even developed a purchase specification to cover the required chemical mixture. However, soon after the engines were placed in service, innumerable reports were received of severe waterside damage despite the special treatment. The most serious damage occurred in circumferential grooves on the cylinder cavities of the Type 355, T-71 aluminum block adjacent to the O-ring liner seals which

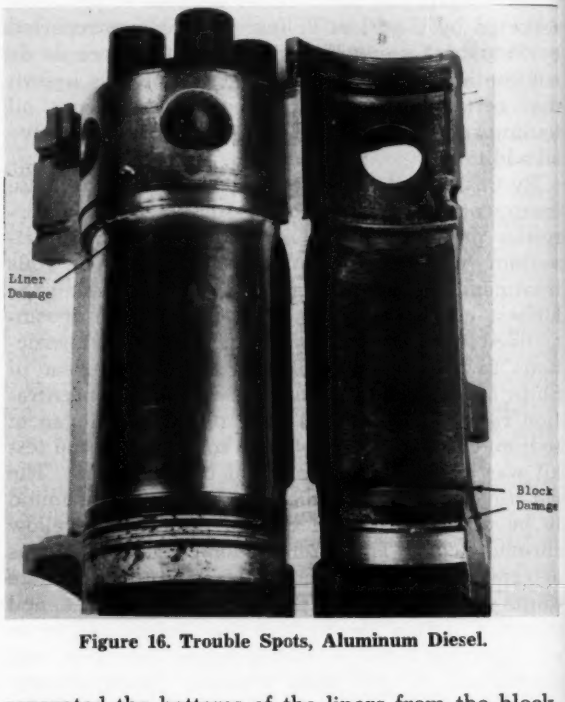


Figure 16. Trouble Spots, Aluminum Diesel.

separated the bottoms of the liners from the block. There also were wasted areas on the tops of the chromium plated steel cylinder liners. The locations are shown in Figure 16.

The nature of this damage is illustrated in Figures 17 and 18. It was characterized by a deep honeycombed appearance of the metal and almost complete absence of corrosion products in the damaged areas. All of the damaged areas were sharply defined and highly localized. The line of greatest attack was at right angles to the center line of the crank shaft and there was more damage on the thrust side. There was ample evidence to indicate that this honeycombing had proceeded with amazing speed in certain instances. Some engine blocks were virtually ruined by a few hundred hours of operation. This type of damage did not originate with the Navy's aluminum diesel. The literature shows many instances of similar troubles in cast iron tractor engines and in locomotive diesels. Many of these cases

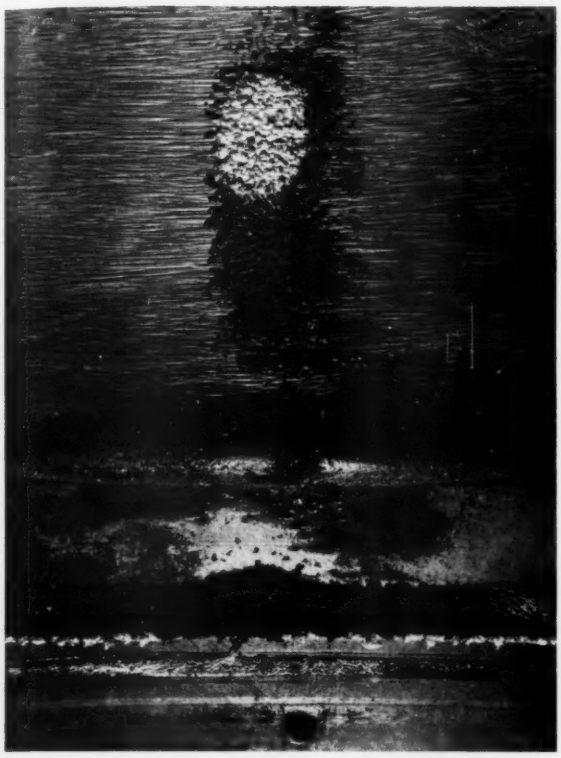


Figure 17. Block Damage, Aluminum Diesel.

have been explained and corrected. Design always was found to be a major factor, but never the only factor.

Originally, there was a tendency for Navy water technologists to blame designed faults for the aluminum engine damage and for designers to blame water treatment. This was fortunate because it touched off extensive investigation in both fields and eventually resulted in improvements in both.

To determine what part of the damage could be charged to mechanical effects (particularly cavitation) instead of water treatment, the Experiment Station's Noise, Shock and Vibration Laboratory made vibration measurements on a 12-cylinder aluminum diesel engine operating in the Internal Combustion Engine Laboratory. These studies showed the expected extremely complex vibration spectrum characteristic of internal combustion engines. Frequencies ranging from about 1400 to 8700 cycles per second and an average absolute displacement (double amplitude) of 0.0023" at 2900 cycles were observed. Liner vibration studies showed that the major components were in the range 2800 to 3000 c.p.s. These measurements left little doubt that vibration was severe enough to cause cavitation in the affected areas and that piston slap is the major contributing factor.

Cavitation was confirmed by inserting plugs of various metallic and nonmetallic materials through the engine block so as to expose them in the vulnerable areas. Typical examples of these plugs after exposure to normal engine operation are shown in Figure 19. The honeycombing of non-metallic material (polystyrene) as well as metallic materials shows that mechanical action was a major contributing factor in the cylinder damage.

Following the confirmation of cavitation effects, the Metals Laboratory conducted cavitation tests on numerous materials to determine if this type of metal damage could be reduced by water treatment. These tests were made with the magnetostriction vibration apparatus shown in Figure 20. In this apparatus the specimen carrier is a nickel tube which forms the core of a high frequency magnetic circuit. Nickel has the property of changing its length when it is magnetized so that when used as the core of a magnetic circuit it develops a high

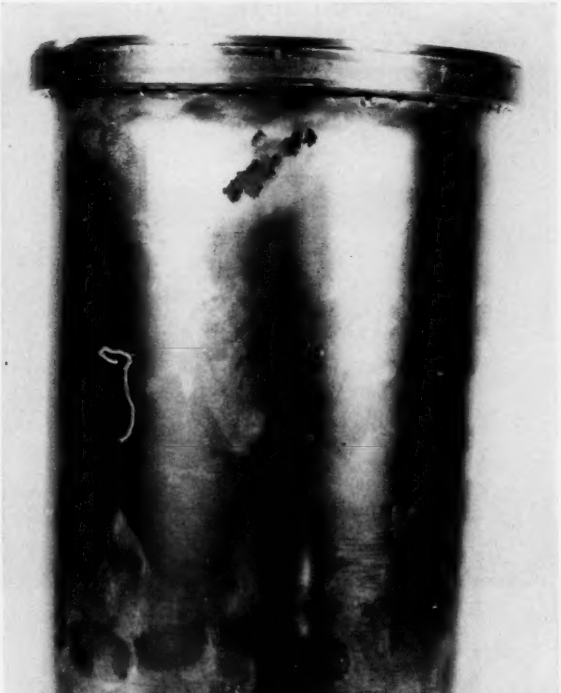
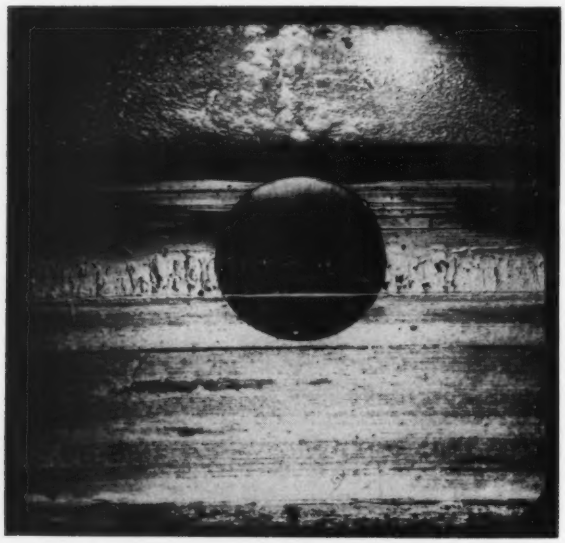


Figure 18. Liner Damage, Aluminum Diesel.



POLYSTYRENE PLUG

ALUMINUM PLUG

Figure 19. Cavitation Test Plugs, Aluminum Diesel.

frequency longitudinal vibration. The magnetic circuit can be tuned to the principal natural frequency of the equipment in question provided there is one. In the Station tests it was operated at 6500 cycles per second, near the maximum observed in the engine, and at amplitudes of 0.001″ to 0.003″. Tests were made with and without opposing anvils of various materials. Various types of water treatment being considered for the aluminum engine were used in preparing the test media.

The magnetostriction tests proved to be much more severe than engine vibration and produced

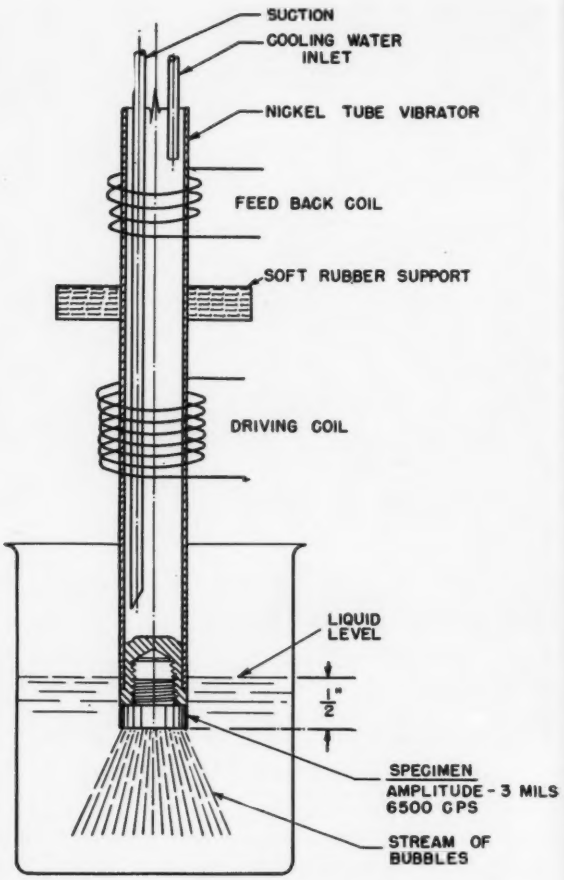


Figure 20. Magnetostriction Cavitation Test Rig.

severe specimen damage in a few hours as compared with hundreds or thousands of hours in engine operation. The fact that they were conducted at continuously high frequency rather than variable frequency with occasional high peaks probably explains part of this difference. However, the tests showed that honeycombing increases markedly with increase in amplitude of vibration, which is related to liner clearance in the O-ring area. They also showed that many cooling system corrosion inhibitors seem to reduce metal loss during cavitation tests, but they failed to show significant differences among them. Thus they did not disclose the most promising inhibitor for actual engine use.

Manufacturers' design studies confirmed the importance of mechanical effects in aluminum engine damage. Cam ground pistons yielded less metal loss. This piston is made slightly out of round so that it has less clearance on the thrust-antithrust axis and takes a more perfect cylindrical shape during operation and thus reduces slap.

Despite the confirmation of mechanical damage, water treatment also was found to have considerable

bearing on the extent of metal loss. The original nitrate-nitrite-phosphate treatment referred to above appeared to offer no protection and a copper poisoner type of treatment (mercaptobenzothiazole) considered by commercial sources to be the next best, was no better. However both soluble oil inhibitor and a soluble oil inhibited glycol type antifreeze appeared to reduce metal loss in the cavitation areas.

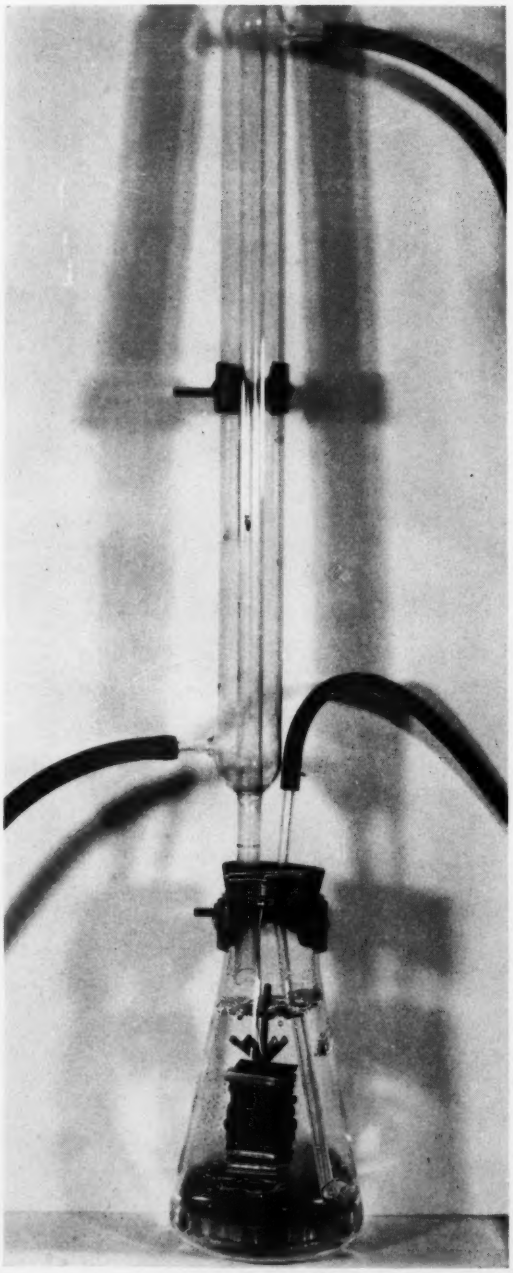


Figure 21. Laboratory Coolant Test Rig.

The effectiveness of water treatment in reducing damage is explained by the fact that so called cavitation damage generally is a complex mechanism involving both mechanical damage from the pounding effect of collapsing bubbles and chemical and electro chemical attack on the metal thus roughened and blasted free of protective films.

The effectiveness of water treatment in reducing aluminum engine corrosion damage (not cavitation per se) was evaluated by extensive inhibitor studies in the laboratory test rig shown in Figure 21, the three cylinder test engine, Figure 22, and both six cylinder and twelve cylinder full size aluminum diesel engines, one of which (12 cylinder) is pictured in Figure 23.

The laboratory tests were made by stacking on insulated bolts all of the materials likely to be encountered in the cooling system of aluminum diesels and immersing these in the test solutions. The test

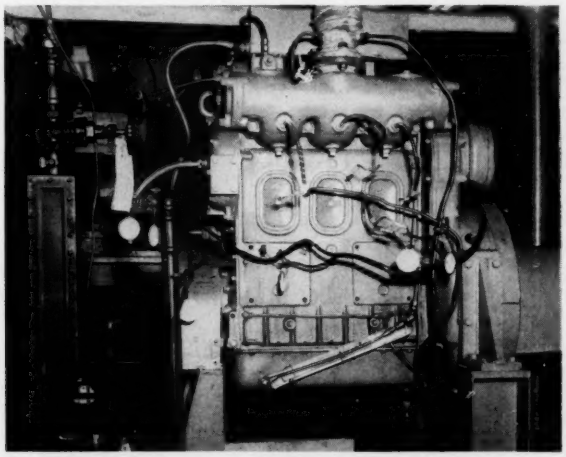


Figure 22. Three Cylinder Coolant Test Engine.

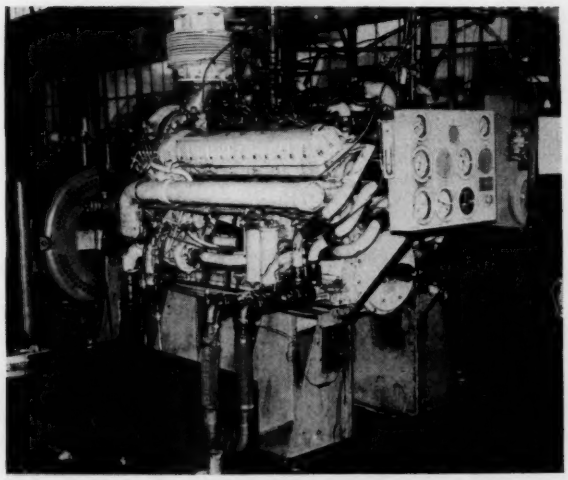


Figure 23. 12 Cylinder Aluminum Diesel.

solution was maintained at expected cooling system temperature and was aerated with compressed air to provide agitation and accelerated oxidation. Sufficient sea water was added to each test flask to yield a chloride concentration of 100 ppm. This is the maximum permitted in Naval service. The reflux condenser shown in Figure 21 prevented evaporation and concentration. These laboratory tests were made for periods of 500 hours or 1000 hours, depending on the performance of the solutions. All laboratory tests were evaluated by noting the effects on both the specimens and the solutions. Weight losses were determined for metal specimens, hardness and swelling tests were made on specimens of hose materials, and the extent of demulsification (soluble oil tests), sedimentation, and specimen fouling were observed.

The three cylinder test engine, which formed the second phase of evaluation, is intended primarily for lubrication oil test by the Fuels and Lubricants Project. The experimental inhibited coolants were used in its cooling system during regular lubrication studies but a metal box with appropriate test specimens pinned to its removable cover was inserted in a water circulation line between the pump and the expansion tank to facilitate corrosion studies. Only metal specimens were included in these tests so that evaluation was confined to weight loss determinations and inspection for localized effects. Daily tests were made on the coolant both to insure proper composition and to study the rate of decline of its corrosion inhibitors.

Water treatment tests on the aluminum prototype engines were made simply by using promising test solutions in their cooling systems, operating the engines as required for other scheduled tests, such as endurance tests, and making visual examination of the engine's waterside after each period.

One test was made in which one bank of cylinders operated with copper piping while the other did not, to accentuate copper ion effects. Stray current tests also were made to study the possibility of electrical effects.

SOLUBLE OIL ONCE MORE

Table V shows the large list of water treatments screened by the laboratory tests. Of these, only the ones which showed promise were used in the test engine. Soluble oils and soluble oil inhibited glycol type antifreeze gave the best aluminum protection in the bench tests and the engine specimen box. There was considerable variation in performance of different brands of soluble oil, particularly with high concentrations of chloride present. Some demulsified rapidly, softened rubber specimens, and allowed appreciable corrosion. Despite this variation the twelve cylinder aluminum engine operated for 4000 hours with one type of soluble oil at 1% concentration without serious block damage. Other factors

TABLE V—*Effects of Cooling Water Treatments on Aluminum*

*Treatment	Degree of Protection (Laboratory Test)
Alkaline Sodium Chromate (700 to 1700 ppm)	Poor
Neutral Sodium Chromate (700 to 1700 ppm)	Fair
Neutral Sodium Chromate (4000 ppm)	Excellent
Sodium Dichromate (10,000 ppm)	Excellent
Sodium Dichromate (100,000 ppm)	Good (Deposit)
Soluble Oil (0.5 to 3%)	Excellent
Soluble Oil (0.25%)	Fair
Ethylene Glycol (Soluble oil inhibitor)	Excellent
Sodium Silicate	Fair (Deposit)
Sodium Nitrate-Sodium Benzoate	Fair
Dianodic Treatment (Chromate-phosphate)	Fair (Poor control)

*Water contained 100 ppm of chloride ion as NaCl.

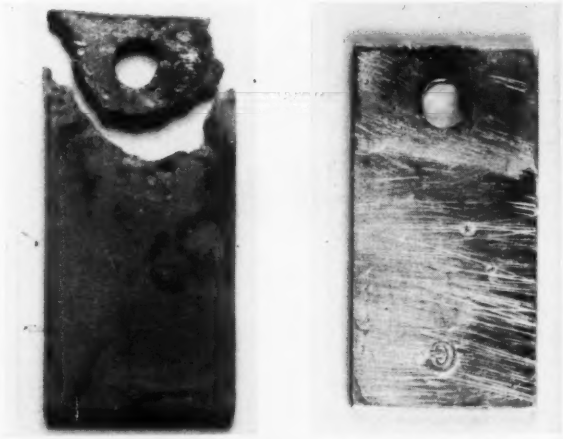


Figure 24. Effects of Alkaline Chromate and Soluble Oil on type 3-S Aluminum.

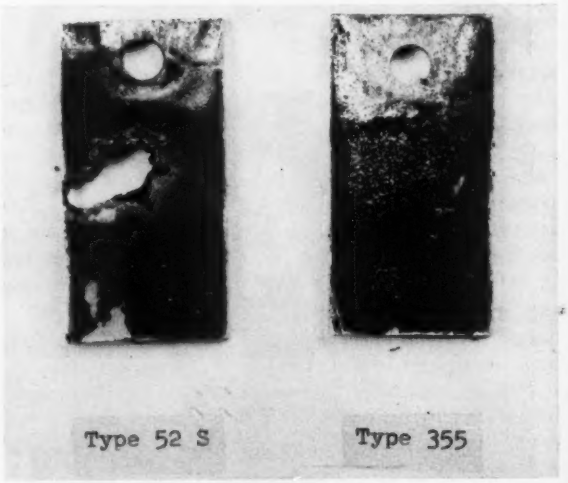


Figure 25. Effect of Neutral High Concentration Chromate on Type 355 Aluminum and 52 S Aluminum.

undoubtedly contributed to the trouble free operation.

The standard alkaline chromate solution presently used in the iron engines was markedly inferior to soluble oil in that it allowed serious galvanic attack on Types 3S and 52S aluminum in contact with steel. Figure 24 compares this damage with the almost perfect protection obtained with the best soluble oil (1000-hour engine test). Type 355-T71 engine block aluminum was not available for comparison when these tests were made.

High concentration neutral chromate (4000 ppm CrO4 at pH 8) was as good as the best soluble oil for protecting Type 3S and Type 355-T71 aluminum but gave very poor results with Type 52S aluminum (piping material). Since the Navy's aluminum engine blocks are Type 355-T71 aluminum, this treatment could be used whenever an oil-free water is desirable. Figure 25 shows the effects of this treatment.

The remaining treatments either yielded more metal loss than soluble oil and high concentration chromate or left objectionable deposits of the type shown in Figure 26. There was no evidence that the copper poisoner treatments reduced corrosion or even that copper ion (10 ppm) increased it, despite the many theories to that effect.

In view of the apparent superiority of soluble oil for reducing corrosion in aluminum engines, service

Figure 26. Objectionable Water Formed Deposits, Proprietary Treatment.

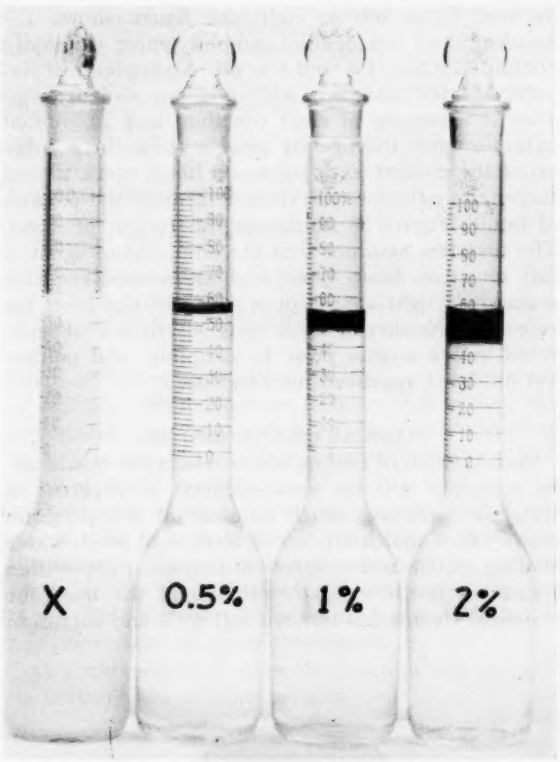


Figure 27. Salt Out Test for Soluble Oil.

tests were authorized in six mine sweeper engines each of the Atlantic and Pacific Fleets. The best soluble oils discovered in the laboratory tests were sent to these ships with detailed instructions and samples presently are being returned periodically to the Experiment Station to insure adequate soluble oil control, to obtain some information on corrosion rates and to gather information on the overall practicability of the treatment. To the date of this writing all reports received from the Fleet have indicated excellent performance of soluble oil and absence of serious corrosion in the vulnerable areas; however, cavitation damage undoubtedly still is occurring. Analyses of sample coolants submitted with these reports at first showed considerable variation in soluble oil contents. This problem has diminished with increase in experience.

On the basis of this variety of investigations, the Bureau of Ships gave tentative approval for general use of soluble oil in aluminum diesels of the Fleet and requested the Experiment Station to develop suitable control tests for shipboard use. The test first developed is illustrated in Figure 27. In this test, a sample of soluble oil emulsion coolant is treated with salt, generally calcium chloride, in a bottle with a calibrated neck and the quantity of oil originally emulsified is estimated from the thickness of the layer of demulsified oil which rises to the

surface. From left to right the figure shows 1% emulsion and demulsified samples which originally contained 0.5%, 1% and 2% oil. A simpler test developed later consists of adding engine coolant dropwise to a sample of clear distillate in a graduated cylinder until the opacity produced by the soluble oil of the coolant extinguishes a black mark placed under the cylinder and viewed through the column of liquid. Figure 28 illustrates this test in progress. The first test assumes that the emulsifying agent is salt sensitive (soap type) and the second requires a standard light source or a standard emulsion for reference. Neither of these tests will detect oil separated in the engine prior to sampling, and neither yet has been approved for Fleet use.

CLEANING COOLING SYSTEMS

A discussion of cooling water treatment would not be complete without some mention of progress in waterside cleaning which touched off this program many years ago. Adoption of the closed fresh water cooling system and progress in corrosion prevention treatment for it virtually eliminated the need for chemical cleaning to remove salt scale and corrosion products from engines. Consequently, the great variety of "radiator cleaners" marketed for industrial automotive engines have found little market in Fleet diesels. Occasionally a closed cooling system must be cleaned because it has been operated with particularly corrosive or particularly hard water; for example, sea water contaminated fresh water or waste contaminated harbor water. For such custom cleaning jobs, the Experiment Station generally fills the cooling system with a ten percent solution of citric acid or ammonium citrate and operates the engine for a short period (one hour or less) to provide circulation and elevated temperature. Obviously such cleaning must be done under the supervision of one who is experienced in chemical cleaning.

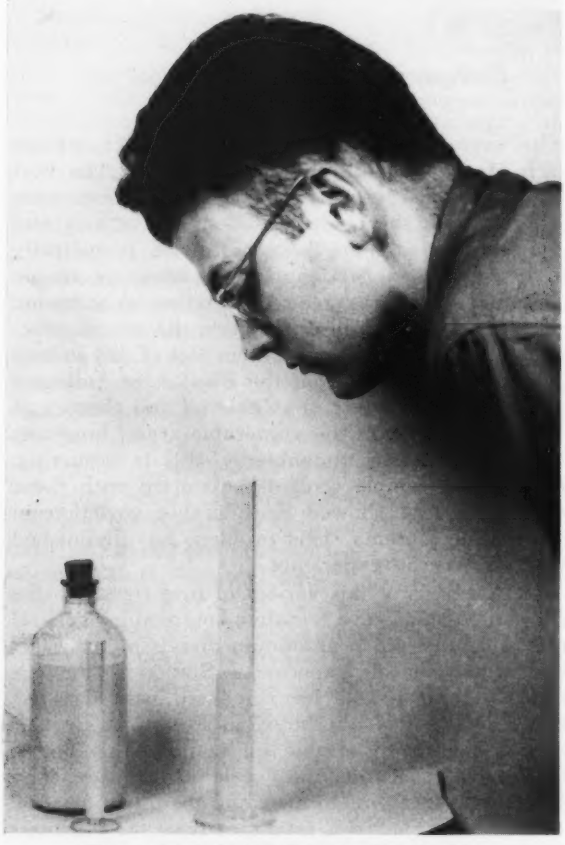


Figure 28. Extinction Test for Soluble Oil.

It also occasionally is necessary to remove organic rust preventive, lubricating oil or demulsified soluble oil from the fresh water cooling circuit. During the evolution of the Naval diesel, a variety of alkaline solutions and organic solvents including lye, soda ash, kerosene, diesel fuel and carbon tetrachloride were used for this purpose, generally on experimental or special approval bases. Recently the Station tested the effectiveness of a sodium silicate-Igepal (detergent) mixture in removing both rust preventive and demulsified oil. This is the same mixture prescribed in Chapter 9 of the Bureau of Ships Manual for removing Grade III rust preventive from the watersides of steam boilers during reactivation. The treatment is applied to diesels by filling the fresh water cooling system with the proper mixture, operating the diesel for two hours at normal temperature, draining the cleaner and flushing with fresh water. This is a mild cleaner which can be used by Fleet personnel. The Bureau currently is issuing instructions for its use. It is very effective in removing oily residues.

The open sea water cooling systems of diesel engines (secondary side of closed systems) always have presented a cleaning problem. The first cleaner recommended by the Experiment Station for cast iron sea water headers (5% HCl and 4 to 6 hours circulation) used no inhibitor and could not be used for steel headers. A strong (2 lb. per gallon) hot solution of trisodium phosphate was recommended for that purpose.

A few years later the Bureau adopted a procedure for cleaning sea water sides of cooling systems with pyridine inhibited 10% hydrochloric acid. Pyridine was not a particularly good acid corrosion inhibitor, but it was the best known to the Navy at that time. This procedure continued in use until 1948 when reports of perforation in Harrison-type heat exchangers during cleaning led to abandonment of acid cleaning completely.

In 1951 the Experiment Station reopened acid cleaning studies at the Bureau's request. Work was

concentrated on the Harrison heat exchanger since this had been the sensitive member. Hot sea water (160°F), hot inhibited 0.25 normal hydrochloric acid and hot 1% soda ash neutralizing solution were circulated through a new heat exchanger in that order for 19 cycles and a total of 38 hours of acid exposure before a leak developed. This leak was in a poorly made soft soldered seal between the copper-nickel core and the bronze shell. However, analysis of the cleaning solution showed appreciable pick-up of lead and tin solder components. Since 19 cleanings probably would not be required in less than 20,000 hours of engine service, this method was considered acceptable and has been adopted for Fleet use.

Incidentally the inhibitor used in this new cleaning method is markedly superior to the once popular pyridine.

DIRECTION OF PRESENT RESEARCH

Developments during the past quarter century have provided adequate cooling water treatments and tests for the conventional iron diesel engine. Consequently, present studies are concerned primarily with the relatively new aluminum engine where Fleet service has not yet proved the merits of the tentatively approved treatment. The current project is to develop suitable purchase specifications for the soluble oil type coolant inhibitor.

As insurance against unforeseen difficulties with soluble oil inhibitors and the first alternate, high concentration neutral chromate, new chemicals also are being studied. High concentration acid chromate (sodium dichromate) already has been tested in the laboratory rig with good results. A 10,000 ppm concentration at about pH 5 gave excellent corrosion inhibition for aluminum with no sign of objectionable deposition. A 100,000 ppm concentration at about the same pH was just as effective in corrosion control, but appeared to produce objectionable deposits on the metal surfaces.

Several types of dianodic treatments also have been investigated in the laboratory test rig. Dianodic treatment consists of low concentration mixtures of phosphates and chromates. Industrial experiments have shown that such combinations are much more effective than higher concentrations of chromate alone. Certain metallic additives, such as zinc, are reported to improve dianodic protection. The Station's tests to date have not confirmed these claims, presumably because of improper control of phosphate and chromate concentrations in the presence of sea salts. While further tests on this system are anticipated, the apparent need for relatively close control is an objectionable feature from the standpoint of Naval service.

TABLE VI—*Relative Effectiveness of Cooling Water Treatments*

Treatment	Approximate Penetration, Inches per year, Iron Specimens, 1000 hours
(A) Distillate plus Chloride Ion (100 to 1700 ppm)	0.10
(B) A plus original TSP-Starch Treatment	0.01
(C) A plus 200 ppm CrO_4 at pH 8 to 10	0.005
(D) A plus 700-1700 ppm CrO_4 at pH 8 to 10	0.0002
(E) A plus 40% Soluble Oil Type Glycol Antifreeze	0.00005
(F) A plus 1% Best Soluble Oil	0.00002

Treatment of aluminum engines with nickel and cobalt salts is perhaps the latest item to appear on the horizon. These treatments are said to prevent corrosion by plating effects on the waterside surfaces. Time has not yet permitted accumulation of adequate data on these treatments.

Organic inhibitors other than soluble oils also will be investigated as time permits.

HINDSIGHT

This development of cooling water treatment for Naval diesel engines has been a cyclic program of approval and reapproval of a relatively small number of inhibitors. However the overall quality of cooling water treatment has crept steadily upward as shown by Table VI. Every apparent shortcoming of a given treatment has led to renewed development studies and further improvement through revision of chemical concentrations, simplification of control tests or improvement of instructions.

It is unreasonable to believe that any water treatment ever will solve all of the engine cooling water problems of the Fleet. A reasonable hope is that approved treatments will extend cooling system life to the expected useful life of the engine in a large percentage of cases. The general absence of corrosion troubles in the iron diesel engine during the past decade and the recent improvements in treatment of aluminum diesel engines indicate that we are approaching this goal reasonably well.

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.
Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

"TRANSACTIONS INST. MARINE ENGINEERS"

DEVELOPMENTS IN MARINE ELECTRICAL INSTALLATIONS

ACKNOWLEDGEMENT

A. N. Savage, Assistant Superintendent Engineer (Electrical), Royal Mail Lines, Ltd., is the author of this article which was published in the June 1957 edition of the "Transactions of the Institute of Marine Engineers." Abridged.

INTRODUCTION

IN CONSIDERING the preparation of this paper it was appreciated that the subject of most interest was that related to a.c. installations, but if the reasons for such a system are to be clearly understood it is necessary to start at the beginning and proceed step by step. On deciding to proceed on these lines, it was also realized that the paper could not be effective without a little outspoken comment; such comment, however, is considered to be constructive criticism and privileged by virtue of qualification and a lifetime of experience in the operation and maintenance of electrical installations.

In the past these installations have chiefly been developed by the shipbuilder and equipment manufacturers to which ship-owners' representatives have in general acquiesced, and it is in the interest of both shipbuilders and equipment manufacturers to maintain the *status quo*.

There is a growing school of thought that the term "marine" is often misapplied and it was encouraging to note in the Institute's Transactions [1] the observation of a progressive shipowner that "In some costing departments the word 'marine' seemed to mean an automatic 30 per cent increase above the prices for similar equipment destined for land use." Such an observation is perfectly true.

If real progress is to be made, if the shipowner is to reap the economic benefits which he is entitled to receive by the adoption of new ideas and the use of different materials, a radical change must take place in the attitude towards marine electrical engineering. It must be recognized by all for what it is, a specialized subject, and the shipowner must have on his staff a person who by virtue of his technical qualifications and practical experience can speak the same language, sometimes, it may be said, better than the builders' and sub-contractors' electrical experts.

That an entirely different approach should be made is recognized in certain quarters by the very fact that today the shipowner has very strong representation, through his electrical representatives, on the major national technical committees.

D.C. DEVELOPMENT

Previous to the advent of the motorship, electrical installations were of a simple nature, and consisted of electric lighting, cabin fans, a small number of ventilating fans and possibly one or two electric toasters, the system operating at 110 volts with earth, or hull, return, the average 15,000 ton passenger/cargo liner having a total generating capacity of some 300 kw.

With the coming of the Diesel-propelled vessel it became desirable to adopt electrically-driven auxiliaries for engine room, steering gear and deck machinery, and the only logical step to take, and which was taken, was to double the operating voltage, and so the 220-volt double-wired system became the standard, thus reducing the weight, volume and cost of equipment relative to power generated, distributed and utilized.

In those early days of the motorship the total generating capacity of a 10,000 ton, twelve passenger cargo liner was some 400 kw. Then, electricity hav-

ing proved to be successful for auxiliary purposes, the next step was to utilize it for cooking and heating services, and in the mid 1920s the position was reached where a 20,000-ton passenger liner had a generating capacity of 1,600 kw. Another development was the installation of electrically-driven refrigerating compressors and the substitution of electrically-driven fans for air cooling in lieu of brine piping.

As a further indication of the growth of electrical installations it is of interest to record that the company with which the author is associated is replacing a class of vessel built in 1928, the generating capacity of these early ships being 800 kw, whereas the capacity of the replacements will be 3,500 kw.

Generating capacity alone is not a true indication of the size of an installation; the total connected load will be two to three times the generating capacity according to the type and class of ship.

Even now there are no signs that we have reached the saturation point; standards of lighting and heating are increasing, additional items are being fitted for hotel and cooking services, while another question to be faced by the shipowner is that of air conditioning, not only for passenger accommodation, but also for the crew.

As the demand for power has increased over the years, and still increases, it has been met by continually increasing the size, and hence the weight and space occupied, of generators, cables, control and switch gear. No attempt whatsoever has been made towards a better and more economical utilization of valuable raw material, or to reduce weight/kw or space occupied. The world demand for copper results in the maintenance of a very high price level. Class "A" insulation still remains the generally accepted practice for marine electrical machines, although far more economical alternatives are available. Motors are still designed on a full-load plus sustained overload rating, though it is only fair to state that this question is under discussion. Control gear has over the years become more elaborate, and hence, not only more costly, but more troublesome.

The net result of all this growth, rather than development, results in larger, heavier, more costly and more troublesome installations.

GROUND FAULTS

The tracing of ground faults becomes increasingly difficult the larger these installations become. A ground fault left untraced is a potential fire hazard should a second fault develop on the opposite pole, According to the textbook, two grounds, one on each pole, should create a short-circuit and fuses should blow or circuit breakers open. A ship is a live, moving, working body, and such a combination of grounds can result and have resulted in arcing taking place and fires have developed. Such grounds on the other hand may result in tracking taking place which can once again develop into fires.

A combination of ground faults can arise whereby such circuits as electric heaters become energized, though switched off; motors with automatic controllers may also be energized although the control switch is in the "off" position. Considerable thought has been given to this problem, but there is no easy and effective manner of locating such faults on large d.c. installations. With a.c. installations this problem can be reduced; in fact it could almost be eliminated if economic considerations were not taken into account.

SHORT-CIRCUIT PROTECTION

This is a question which requires very serious consideration. When a short circuit takes place the magnitude of the short-circuit current depends on the capacity and number of generators on the busbars and the resistance or impedance of the circuit.

For d.c. generators the initial short-circuit current can be taken as being ten times full-load current, but with the a.c. generator the initial value of short-circuit current, when a complete short circuit is applied to the terminals of the alternator, depends upon the internal impedance of the alternator and whether the current flow is symmetrical or asymmetrical.

In modern alternators the internal impedance is usually of the order of 10 per cent. This means that if the machine is operating (at any load or power factor) at normal voltage, the instantaneous value of short-circuit current is ten times full-load value (R.M.S. amperes) if the short circuit is applied at the instant which results in a symmetrical current flow, or twice this (R.M.S. amperes) if the short circut is applied at an instant which results in an asymmetrical current flow. The d.c. component of the asymmetrical short-circuit current decays rapidly during the first cycle. Because of this rapid decay and because the circuit breaker protecting the alternator does not operate instantaneously, it is generally sufficient to assume that the circuit breaker will be called upon to rupture only about 80 per cent of the initial value of the asymmetrical short-circuit current. The full value, however, should be taken into consideration when estimating the mechanical stresses set up when closing a circuit breaker on to a short circuit.

The total contribution towards the magnitude of the current also depends upon the size and number of motors running at the time the short circuit takes place, the motors feeding back into the fault.

In the author's opinion, further research must be carried out in order to solve the question of short-circuit current values for various installations, and in order to ensure that correct protective equipment is fitted. It is suggested that the following values should be accepted in estimating short-circuit current values until more detailed research has been carried out:—

D.C. generators	10 times rated current
D.C. motors	6 times rated current
A.C. generators (10 per cent impedance, symmetrical current flow)	10 times rated current

A.C. generators (10 per cent impedance, assymmetrical current flow) ..... 20 times rated current
A.C. motors ..... 3 times rated current

TABLE 1—*Comparative values of short circuit current for 220--volt D.C. and 440-volt A.C. 3-phase.*

System	Generator capacity	Short circuit, amperes	Motor capacity, h.p.	Short circuit, amperes	Total short circuit, amperes
220-volt d.c.	2,400 kw	109,080	1,000	24,000	133,080
440-volt a.c. 3-phase	3,000 kva	39,360 (symmetrical)	1,000	4,800	44,160
440-volt a.c. 3-phase	3,000 kva	78,720 (asymmetrical)	1,000	4,800	83,520

In order that this problem may be appreciated, Table 1 is given showing the total prospective short-circuit currents for a typical installation. It is assumed that five 600-kw generators are installed and that at no time are more than four connected to the busbars, and that 1,000 h.p. of motors are running at the time of maximum load. The table shows the values for 220-volt d.c. and 440-volt 3-phase a.c. symmetrical and asymmetrical current flow.

The true meaning of these figures is that the protective devices, such as fuses and circuit breakers, must be designed to cope with these values of short-circuit current, and hence for the 220-volt d.c. system such devices have to give protection against a prospective current far greater than the "asymmetrical" short-circut current of the 440-volt a.c. system.

Figure 1(a) shows four 750-kva 3-phase 440-volt alternators connected to the main switchboard busbars, and values of short-circut current are given when short-circuit faults develop at points (a), (b) and (c), the latter being on an outgoing feeder circuit.

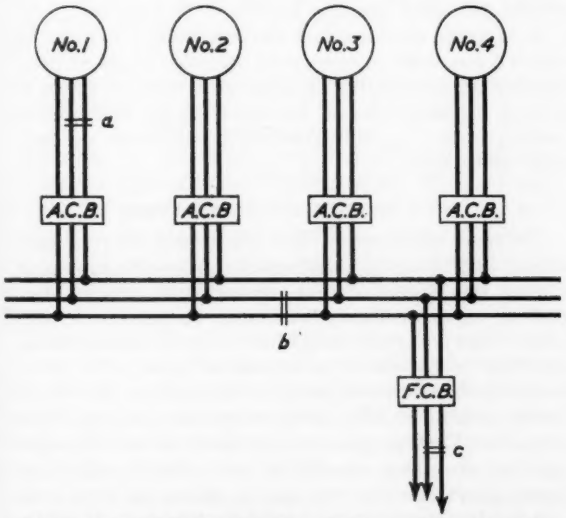


Figure 1(a)—Four 750-kva 400-volt three-phase alternators each of 10 per cent impedance.
ACB—Alternator circuit breaker
FCB—Feeder circuit breaker
a, b, c } Points of short circuit fault

The asymmetrical short-circuit current of each alternator is 19,680 amperes, and with a fault at point (a), No. 1 alternator circuit breaker will have to deal with a fault current of 59,040 amperes; that is, the total fault current of the remaining three machines. With a fault at point (b) the alternator circuit breaker will only have to deal with the short-circuit current of its respective alternator, namely, 19,680 amperes. A fault at (c) results in all four alternators feeding into the fault, and the total short-circuit current the feeder circuit breaker has to cope with is 78,720 amperes.

It has been shown in Table 1 that the total instantaneous short-circuit current for the 220-volt

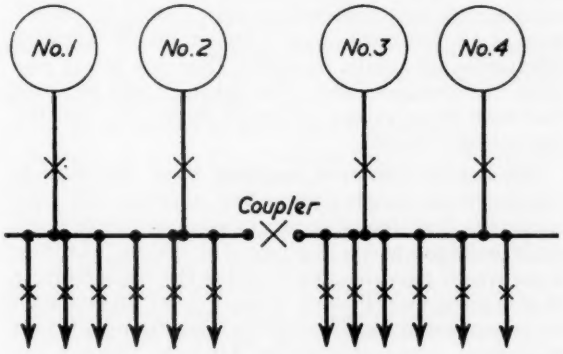


Figure 1(b)—Four 600-kw 220-volt direct current generators.
Total short circuit current with coupler closed, 109,080 amperes.
Total short circuit current at each section with coupler open, 54,540 amperes.

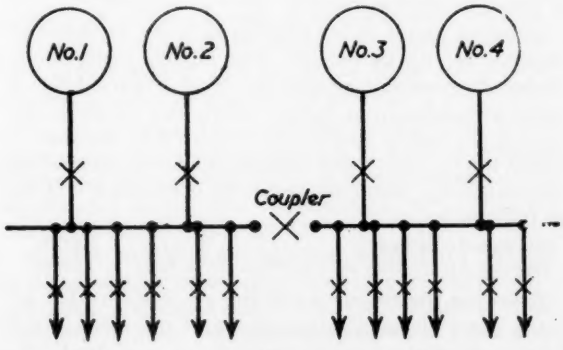


Figure 1(c)—Four 750-kva 440-volt three-phase alternators.
Total short circuit (asymmetrical) with coupler closed, 78,720 amperes.
Total short circuit current at each section with coupler open, 39,360 amperes.
Total short circuit current (symmetrical) at each section with coupler open, 19,080 amperes.

d.c. installation quoted is 109,080 amperes. As far as fuses are concerned the highest category of duty is one where the fuse will operate efficiently with a prospective current of 33,000 amperes. It is obvious therefore that to fit such fuses on a main switchboard where there is a prospective current of over 100,000 amperes is, to say the least, potentially dangerous—others have used the word "terrifying." As far as circuit breakers are concerned the author knows of no hard and fast rule with regard to stated operating efficiency.

It does appear therefore that the industry is building up installations with astronomical short-circuit current values, closing its eyes, and hoping for the best.

It will be noted from Table 1 that if an a.c. supply at 440 volts is adopted, there are two values of instantaneous short-circuit current, depending on whether the current wave is symmetrical or asymmetrical. There is a divergence of opinion as to whether the asymmetrical current should be considered at all, but until more is known about operating efficiencies of circuit breakers, then the worst possible circumstances should be taken. It will be noted that both these values are much lower than for the 220-volt d.c. system.

The marine electrical engineer must endeavor to reduce these large prospective short-circuit currents; the first step as shown is to adopt higher operating voltages and a 3-phase a.c. system. Another point which must be considered is the sectionalizing of the main switchboard. Figure 1(b) shows such an arrangement for 220-volt d.c. and Figure 1(c) an equivalent arrangement for 440-volt 3-phase a.c. From these two figures it will be seen that the total short-circuit current a feeder circuit breaker has to deal with is now reduced to 54,540 amperes on the d.c. system, which is still too high, 39,360 amperes with an asymmetrical current wave with 440-volt a.c., which is more suitable, and only 19,680 amperes if the symmetrical current wave is adopted.

Another factor to be considered is the mechanical stresses set up in busbars and busbar connections under short-circuit conditions. If, in Figure 1(a), a main switchboard is taken where the busbars are spaced six inches apart and supported by insulators every thirty inches, the mechanical force exerted on the insulators under short-circuit conditions will be as follows:—

220-volt d.c. system	2,623lb.
440-volt a.c. system asymmetrical wave form	1,359lb.

Allowing the resonance in the a.c. system, that is, if the short circuit is sustained, and the mechanical frequency of the bars is equal to, or a multiple of, the frequency of the electrical system, the force on the insulators may rise to 2,265lb.

Sectionalizing of the main switchboard, while solving one problem, may introduce further complications. The correct solution for the larger installations may yet prove to be generation at even higher voltages than 440 volts.

A natural question to ask is, what does all this mean in practice? It simply means that if the installation is not properly designed it could result in the loss of a vessel. Protective devices are usually designed and allocated a category of duty on the basis of their rupturing capacity, but a far more important point as far as circuit-breakers are concerned is the making capacity. A closed circuit breaker may quite easily open and rupture a short circuit, but an attempt to close a circuit breaker on a short circuit may just as easily result in the welding-in of the breaker and in the complete shut-down of the installation. It might be opportune at this point to quote from a report on the French vessel *Flandre*.

"The *Flandre*, a transatlantic liner of 20,459 tons, was held up at the entrance to New York harbor in July 1952 by a failure of a technical nature. A commission of inquiry was appointed by the Minister in charge of the French Mercantile Marine. To obtain further details, senators recently adopted the procedure of a special Parliamentary commission of inquiry.

"A short circuit occurred, unfortunately, just at the moment of entering New York, and the circuit breakers, having an insufficient cut-out capacity, were fused: the electrical plant was consequently put out of action for some hours.

"As all services aboard were electric—engine room auxiliaries, steering gear, kitchens, etc.—the vessel was out of control and circumstances rendered the incident both spectacular and unfortunate; had it occurred far from land, it could have been repaired and the delay probably made up, so that failure would not have become known to the public."

It is quite obvious that further research must be carried out with reference to the magnitude of prospective short-circuit currents, and that all types of circuit breakers should be tested by an appropriate testing authority and granted a certificate of category of duty.

MAINTENANCE AND REPAIR COSTS

There is no question that the direct current generator and motor is a vulnerable piece of equipment, due to the effects of dirt, carbon dust, copper dust and oil vapor on the commutator; furthermore, on a large heavy-current machine, a very considerable quantity of carbon is, in course of time, worn away from the brushes and will be retained in the ventilating system, chiefly in the ventilating ducts of the armature. Dirt, copper and carbon dust and oil vapor on a commutator results in carbonized micas and hence short circuits between commutator segments, and finally, if not cleared in time, burned out armature coils.

Again, what does this mean to the shipowener? In order to give some idea of the cost in £ s. d., five cases are quoted of costs involved due to carbonized micas.

(a) 100-kw Generator Armature

The coils were on the point of burning out. A new set of commutator micas were purchased in the United Kingdom and flown out to a port abroad. The armature was landed during the outward voyage for repairs. On fitting the armature on the homeward call, the generator failed to excite. The armature was landed at a second port of call and after ten days' delay in sailing the armature was in working (?) condition. The first contractor did not submit an account in view of unsatisfactory workmanship. The second contractor's account was £700. On return to the United Kingdom, the armature in question was examined and the only prudent step to take was to rewind the armature at a cost of £400. The total cost of repair was £1,172, including the cost of mica, plus ten days' docking dues and ten days' loss of earnings.

(b) 175-kw Generator Armature

Two coils were burned out. The cost of re-insulating two coils and clearing carbonized micas was £1,083, plus 2½ days' docking dues and 2½ days' loss of time.

(c) This was a similar case to *(b)*, being a sister ship —the cost was £1,213.

After two such incidents it was decided to order a spare armature for this class of vessel, the cost being £1,210. Therefore the cost of repairing two armatures was in each case approximately the same as a new armature.

(d) 600-kw Turbo Armature

A ground developed on the armature of a 600-kw turbo-generator due to the commutator back mica "V" ring becoming carbonized. The cost of repair was £3,059 plus three days' docking dues and three days' loss of earnings.

(e) 135-h.p. Motor

Twenty-five commutator micas were renewed at a cost of £436.

A.C. INSTALLATIONS

Suitable as direct-current undoubtedly was for the early shipboard installations where the load was mainly lighting, and small in amount, it is very unlikely that direct-current would be chosen if a clean start could be made in the application of electricity to the various duties met with nowadays on board ship.

There is no doubt that alternators and induction motors are more simple, safe, reliable and economical (both in first cost and maintenance) than direct-current generators and motors. Alternating-current machinery lends itself more readily than direct-current to the adoption of modern insulating materials suited to high temperature, permitting further reduction in weight and bulk. Also, induction motors, especially those with squirrel cage rotors, are much less susceptible to the effects of moisture and dirt in the atmosphere than are direct current machines. Consequently, they can be of the ventilated type for practically every application aboard ship.

Induction motors are inherently constant speed machines and this may be considered a disadvantage, but whereas it may be so from the pump and fan designer's point of view, it is no longer so from the operating angle. The ease with which the speed of a d.c. motor can be adjusted, as distinct from variable speed, gives the designer considerable latitude.

The direct-on started squirrel cage motor can be utilized for all services. In addition to its outstanding advantages of simplicity and great reliability, it is very compact, the combination of motor and control gear requiring less space than with any other type of machine. Also, the extreme simplicity of the control gear, in effect simply a triple pole contactor to connect the motor to the line, permits remote control from a centralized control point. There are also further advantages, as distinct from cost, weight and space, derived from fitting an a.c. installation.

Every maritime nation of importance with the exception of Great Britain is proceeding with such installations, and this being so, and if the above mentioned advantages are correct, then it is pertinent to ask—why are we lagging behind? Such a question can only be answered by being perfectly frank; there are three reasons:

(a) Manufacturers of Electrical Equipment

In view of the low cost of a.c. motors and control gear relative to d.c. one cannot but form the impression that manufacturers view the introduction of a.c. to ship work with much disfavor and endeavor where possible to complicate and therefore inflate the cost of a.c. installations. Furthermore, the manufacturer realizes that there will not be the same demand over the years for spare gear, which is an assured source of income.

(b) The Shipbuilders

Where the shipbuilder carries out his own electrical work, he has been doing so for years long past and is steeped in d.c. working. Alternating current systems do not present any fundamental difficulties, just a different line of thought. There is a growing belief that in many instances the shipbuilders' representatives cannot be bothered. In this connection the author would like to quote from an article[2] which appeared in a technical journal:

". . . Alterations to design and specification. When these occur, owing to the absence of detailed costing, the owner usually finds them very expensive, as the shipbuilder plays safe, *and, in any case, may not wish to make the alterations.*"

In other words, if a shipowner wishes to progress, to do something more progressive, more technically advanced, and more economical than what the shipbuilder has been accustomed to doing for the past fifty years, then it can be killed on price by the shipbuilder if he so desires.

(c) Shipowners' Representatives

The critics of a.c. installations never seem to tire of raising the bogies of increased generator capacity for a.c. as compared with d.c.—the total blackout of

installations due to starting currents of large squirrel cage motors; voltage dips due to starting currents; that the first cost of a.c. will not be less than for d.c. and that saving in maintenance has yet to be proved. Such points do not arise in a correctly designed and fitted installation, and once again, one cannot help but feel that they are raised as a form of scare tactics by interested parties.

Marine electrical engineering has reached the stage where it is a specialized section of shipbuilding and shipowning and it is considered that there are far too many connected with shipowning who are prone to adopt the attitude of "better the devil you know than the devil you don't know."

TYPES OF A.C. DISTRIBUTION SYSTEMS

The following are recognized systems of distribution:

Three-phase, three-wire.

Three-phase, three-wire with neutral grounded.

Three-phase, four-wire with neutral grounded but without hull return.

The voltage limitations with such systems are:

440 volts three-phase for power and cooking services.

250 volts single-phase for single-phase motors and heating.

150 volts to ground for lighting and socket outlets.

Figures 2(a), 2(b) and 2(c) show the connections for these various systems.

Three-phase, Three-wire System (Figure 2(a))

With this system all motors of 0.25 h.p. and upwards and galley ovens and boiling plates may be connected to the 440-volt busbars. Heating and single-phase power must be supplied through 440/250-volt transformers, and lighting circuits through 440/230-volt transformers with the mid-point of their secondaries grounded, or, alternatively, 440/150-volt transformers.

The author considers this to be the ideal system; a dead "ground" can occur and this "ground" may be on an essential circuit such as steering gear, or an engine pump, and yet the system can continue to operate satisfactorily. With schemes of distribution as shown in Figures 2(b) and 2(c), such grounded circuits would be tripped immediately without warning, which could prove embarrassing if not unfortunate. It is essential however to eliminate "grounds" as soon as they are observed.

For the supply to such circuits as electric heating, etc., the transformers should be in the form of three single-phase units connected delta/delta as shown; should one phase fail, the other two will maintain the supply, though at a reduced output.

For lighting circuits where the requirements limit the voltage to ground to 150 volts, there are two alternatives: 440/150-volt delta/delta or 440/230-volt delta/star transformers, the latter with star point grounded.

The 440/150-volt scheme is not so suitable from

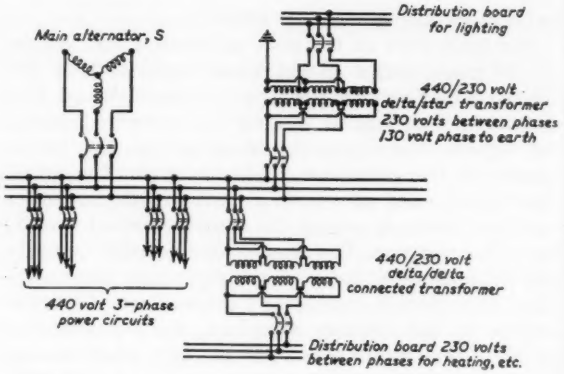

Main alternator, S
Distribution board for lighting
440/230 volt delta/star transformer
230 volts between phases
130 volt phase to earth
440/230 volt delta/delta connected transformer
440 volt 3-phase power circuits
Distribution board 230 volts between phases for heating, etc.

Figure 2-(a)—Three-phase three-wire system, 440 volts.

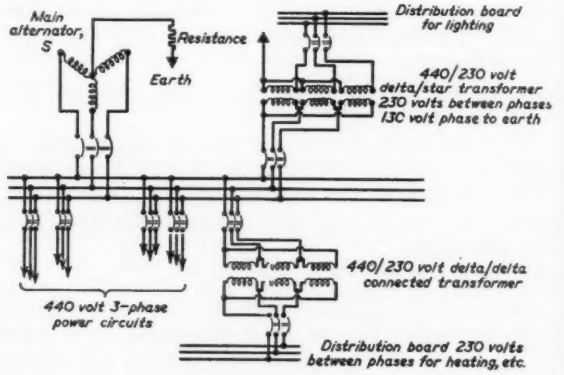

Main alternator, S
Resistance
Earth
Distribution board for lighting
440/230 volt delta/star transformer
230 volts between phases
130 volt phase to earth
440/230 volt delta/delta connected transformer
440 volt 3-phase power circuits
Distribution board 230 volts between phases for heating, etc.

Figure 2-(b)—Three-phase three-wire system; 440 volts, with neutral grounded.

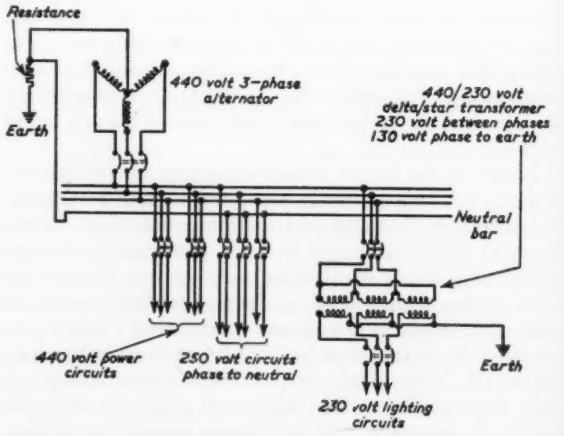


Figure 2-(c)—Three-phase four-wire with neutral grounded.

an economical point of view or from the point of view of utilizing standard 230-volt equipment.

The 440/230-volt delta/star system with star point grounded is not in the author's opinion suitable from a safety point of view. With this point grounded, the fuse should blow or circuit-breaker open when a "ground" fault occurs on the system fed from the transformer. In practice this is not strictly so; it may result in circulating currents through the hull, circuits which are ostensibly switched off become energized, arcing or tracking "ground" faults with their attendant fire risk.

The grounding of this point is in order to limit the voltage to ground from a shock point of view but there is no authority which can state that 230 volts to ground is any more dangerous than 150 volts. If 230 volts to ground is lethal, then the most lethal space today is the British housewife's modern kitchen with its electric refrigerator, cooker, washing machine, electric kettle and laundry iron, all of which are pieces of portable equipment by virture of being connected to a 230 volts to ground supply through socket-outlets and flexible cables, and over and above the equipment mentioned there will be a kitchen sink with water taps, an Ideal boiler and possibly gas pipes for a gas poker, all of which are grounded.

With an ungrounded transformer there will normally be no potential difference to ground; that is, one can make contact with any one line without receiving a shock. On the other hand, with a grounded transformer, there will always be a potential difference of 130 volts. With the ungrounded transformer there will be a potential difference of 230 volts should a very low resistance "ground" develop on one line, but it must be borne in mind that all metallic parts not intended to be alive are themselves grounded and therefore in order to receive a shock one would have to touch a live conductor.

It is pointed out by the critics of a.c. installations that the necessity to install transformers results in additional cost, space occupied and weight carried. In a sense this is true, but a complete installation is being considered, not separate items.

Another point to be considered is the factor of safety. From an examination of Figure 2(a) it will be seen that there is no electrical connection between the secondaries of heating and lighting transformers and the power busbars, or between the transformer secondaries for heating and lighting. In other words, the complete installation is divided into a number of sections, each section being isolated electrically from any other. A ground fault on one section cannot combine with a ground fault on another to constitute a fire hazard. Further, ground fault indication can be wired back to a centralized indicator to indicate which section is grounded.

Another factor in favor of the transformer is that the short-circuit capacity, and hence the short-circuit current of the 230-volt section of the installation is appreciably reduced by virtue of the transformer reactance. Taking four 750-kva machines connected to the busbars as previously, Figure 3 shows the short-circuit capacity and current on the primary and secondary sides of a 200-kva and a 100-kva 440/230 volt transformer, each of 5 per cent reactance.

The short-circuit capacity and current is 30 mva and 39,360 amperes respectively in each case on the primary side but only 3.53 mva and 8,794 amperes on the secondary side of the 200-kva transformer, and 1.87 mva and 4,698 amperes on the secondary side of the 100-kva transformer.

For an equivalent 220-volt d.c. installation, the short-circuit currents at these points would be considerably greater, and would require protective gear of a much higher category of duty.

Three-phase, Three-wire with Grounded Neutral (Figure (2b))

If the neutral point of an alternator is grounded solidly through a low resistance ground connection, a ground fault on any line will not appreciably disturb the potential from ground of the remaining lines, which are tied down to a voltage above ground of

$$\frac{\text{line voltage}}{\sqrt{3}}$$

On the other hand, if the "ground" on the line is a very low resistance one, the fault current that flows will approach the short-circuit current of the alternator. If the neutral point is grounded through a resistance, the effect both in regard to potential of lines above ground and the value of fault current will lie between the extremes of the entirely ungrounded neutral and the completely grounded neutral.

If the neutral point of an alternator is solidly grounded when a severe "ground" occurs on any line, the very heavy current that will flow on the line will usually trip, not only the feeder circuit breaker involved but also the main alternator circuit breaker, unless very effective discriminative protection is provided, such as, by heavily time-lagging or otherwise restraining the alternator circuit breakers and so allowing the faulty feeder to be isolated from the system by its own circuit breaker. It is primarily to render this discriminative feature possible that current-limiting resistances are often inserted between the neutral point of the alternator and ground.

It will be realized therefore that should a "ground" occur on an essential circuit, the circuit will be isolated from its source of supply immediately, which might prove to be unfortunate.

When considering this scheme of distribution, it is worth while to refer to requirements regarding electrical steering gears, which are as follows: The circuit breakers are to be set for tripping at 200 per cent full-load and no overload trips are to be fitted

in steering gear control equipment. This is to ensure that power is maintained even to the point of burning out the motors. It is obvious that if a grounded neutral system is adopted the above requirements for steering gear cannot be met.

Further, with the neutral grounded, a relatively high resistance fault can occur which may be a tracking or arcing fault, and hence a fire risk.

Three-phase, Four-wire System with Grounded Neutral (Figure 2(c))

A four-wire system should never be installed unless the neutral is grounded, otherwise a combination of ground faults may occur whereby the line voltage of 400 volts can be applied to a section of 230-volt equipment.

With this system the neutral is brought to a fourth busbar of the main switchboard and is grounded, and the voltage between any phase and neutral is

$$\frac{\text{line voltage}}{\sqrt{3}}$$

which gives line to neutral voltage of 250, 230 and 220 for alternator voltage of 440, 400 and 380 respectively.

With this system, power circuits are connected across the three phases, or lines, and the 230-volt circuits across any one line and neutral, as shown in Figure 2 (c). The only transformers required are those for the lighting circuits, and not even these if the limitation of voltage to ground can be dispensed with. The saving in cost of transformers is to a great extent offset by the additional cost of cable and switch gear, the possible failure of supply to essential services, and attendant fire risks.

From the foregoing remarks it will be apparent that the system most favored by the author is a three-phase three-wire system with ungrounded neutral, with power circuits fed at 440 volts, and delta/delta connected transformers for all 230-volt circuits and without any grounding of transformer secondaries.

Such a choice of system gives the following advantages: —

1. Maximum reliability of supply to essential services.
2. Reduction of short-circuit faults to a minimum.
3. Magnitude of short-circuit currents reduced to a minimum, allowing a lower category of duty of protective devices to be fitted.
4. Easing to a minimum the time taken and trouble experienced by operational staff in locating ground faults, and so reducing fire hazards.

GENERATING PLANT

For ships' installations the alternators will normally be of the rotating salient pole type and in order to obtain the maximum standard of reliability it is recommended that such machines should have a comparatively low voltage (say 100 volts) excitation; they should be of the duct-ventilated type with filters in the inlet ducts.

Alternators today are not called upon to operate under overload conditions and therefore should be designed for C.M.R. (continuous maximum rating) instead of load plus sustained overload. The insulation should be Class "B," which allows a higher temperature rise, instead of the commonly accepted practice of Class "A." The combination of these two points results in a machine which is cheaper in first cost and is less in weight and occupies less space.

In assessing the alternator capacity for any particular installation it is only necessary to work on a similar basis as d.c. installations, that is, an estimation of the maximum sea and port loads. Having decided on the capacity of the generating sets in kw, one must take into consideration the question of power factor. If it is decided to adopt the generally accepted standard of 0.8 power factor, then the kw become in kva 25 per cent more; that is, a 600-kw set can be quoted at 750 kva at 0.8 power factor. This does not mean that the prime mover has to cope with an additional 25 per cent of power but that the alternator has, from a temperature rise point of view, to deal with an increase of 25 per cent in current.

This is a point about which one may be misled; generators as such have not to be larger for a.c. compared with d.c., which is a point that can be played upon. In discussing a proposed a.c. installation with a shipbuilder it was decided that 600-kw alternators were suitable; allowing for a power factor of 0.8 the alternator became 750 kva, which is after all only another way of expressing the same thing. The shipbuilder than said it was necessary to increase the generating plant by 25 per cent. On being asked why, the reply was because it was an a.c. ship. The suggestion was utterly preposterous and was rejected but this again is one of the bogies that certain people raise.

A point which does require clarifying is the rating of marine Diesel engines for auxiliary purposes. The only reference in the Classification Rules is that:

The rated output in b.h.p. is to be the load required to drive the generators and all direct-coupled auxiliaries at their continuous maximum rating for a period of twelve hours when working with a barometric pressure of 30 inches of mercury and a surrounding air temperature of 62°F.

Where such engines are coupled to generators for auxiliary purposes, the generators are rated for continuous day and night running with a surrounding air temperature of 113°F. With the prime mover and the generator forming a combined unit, it is not logical to have such widely different conditions for rating purposes.

The specified conditions given in B.S. 649-1949 are that the rated output of the engine shall be the load in b.h.p. which it is capable of carrying for a period of twelve hours at rated speed when working with:

Mean barometric pressure of 29.5 inches of mercury.

Ambient temperature at intake of 85°F.

Humidity, 0.6 inches of mercury vapor.

An engine rated under the above conditions would have to be derated for temperature, humidity and day and night running where adopted for marine purposes, and the deductions for a machine running more than 24 hours in an ambient of 113°F. would be as follows:—

	per cent
(a) Deduction for temperature	5.6
(b) Deduction for humidity	5.7
(c) Deduction for day and night running	10.0
Total deduction	21.3

This seems to be a realistic approach to the rating of marine auxiliary Diesel engines for it is often found in practice that marine engineers are loath to operate their generators at more than 70-75 per cent load due to the high exhaust temperatures obtained.

It is not proposed to discuss the operation of alternators in parallel, voltage regulation, the sharing of kvar loading and such other matters, for these points have already been covered in an Institute publication.[3]

Various developments have taken place to eliminate the voltage regulator. Compound-wound synchronous generators have been developed which are self-regulating but these have been of the stationary field type and of relatively small capacity. Another development has been the exciterless synchronous generator compounded through current transformers and rectifiers.

In discussing the reaction of the supply system to large variations of load, it should be noted that kw-load peaks will invariably produce a drop in the system frequency owing to the reduction in the speed of alternator prime mover, and the active power peaks of the alternator are eased by the induction motors connected to the system, which momentarily operate as generators and feed back.

At the same time voltage regulators are available, which, with the alternator unloaded (the most stringent condition), a load representing 50 per cent of the alternator full-load current at a low power factor can be thrown on and off, and the initial voltage variation will not exceed 10 per cent; and the voltage will be restored to within plus or minus 2½ per cent of normal in less than 0.5 second.

In view of what has been said above, the direct-on starting of even the largest squirrel cage motors met with on board ship, and voltage variations, do not present any difficulties.

SYNCHRONIZING OF ALTERNATORS

This is sometimes considered to be a problem, but is actually a simple operation, and only becomes a problem in the minds of those who are not conversant with the underlying principles. When two d.c. generators are being put in parallel, it is only necessary to equalize the voltages to enable the switch to be closed without causing the generator to deliver or receive any load. However, when paralleling two alternators, it is necessary to ensure that not only are the voltages equal but that they are also in phase with each other. This latter requirement may be met in two stages:—

(a) The two voltage vectors (incoming and running) must be rotating at exactly the same speed.

(b) The vectors must be in phase with each other; that is, the two voltages must be reaching their positive maximum values (or any other point in the cycle) at exactly the same instant.

These requirements must be obtained each time the sets are paralleled and to enable this to be easily determined a synchroscope is employed.

SELF-SYNCHRONIZING OF ALTERNATORS

If an alternator is to parallel with a relatively large system it may be sufficient to provide the alternator with low-resistance, pole face, damping windings and to arrange for the alternator to be switched directly on to the line when it has been brought by the prime mover up to approximately normal speed. Immediately after it has been switched to the line, the excitation must be applied and the alternator will synchronize. With a normal machine, relatively large currents will be drawn during this process, but by suitable design, the magnitude of these synchronizing currents may be limited, though the inherent voltage regulation would be impaired.

If the capacity of the system to which the alternator is connected is not sufficient to withstand the heavy synchronous currents drawn in this fashion, it may be desirable to arrange the switching to the line through a current limiting reactor or choke coil until the machine has been excited and synchronized, after which the reactor may be short-circuited. If, on account of synchronous current draw limitations, neither of these methods is acceptable, automatic synchronizing may be resorted to whereby the usual operations associated with manual paralleling are performed through the medium of automatic relays and switches. The technicalities of synchronizing is dealt with in more detail in an Institute publication.[3]

MAIN SWITCHBOARDS

Alternator circut breakers for the larger capacities should be electrically closed by means of a solenoid coil, though at the same time they should be arranged for hand operation in conjunction with one or more protective features whereby the circuit breaker is tripped out automatically when abnormal conditions arise. Protective features commonly employed in conjunction with circuit breakers controlling alternators include:—

Overload releases which, for small capacities, may be current actuated and function by operating directly on the circuit breaker mechanism or, for larger capacities, a separate current or power (watt)-operated relay may trip the circuit breaker through the medium of a shunt tripping coil.

A reverse power protective feature is usually fitted in the form of a separate relay operating the circuit breaker through the medium of the shunt tripping coil whenever two or more alternators are operating in parallel.

A preferential tripping device is required to ensure that, should the alternators become overloaded, the supply to non-essential services is shed, thus maintaining a supply to those services considered essential for the propulsion and safety of the ship. In d.c. installations the tripping relay is operated on a current basis, the power being directly proportional to the current value. In a.c. installations the relay should be power (watt)-operated, as in this case the power developed is proportional to current and power factor. With a power factor varying between 0.8 and 0.87 there would be a power variation in tripping of 8.7 per cent if the relay operated on current only.

Voltmeters. When two or more alternators are installed it is necessary to employ two voltmeters, one of which is permanently connected to the busbars to indicate the voltage of the running machines. The other instrument is so arranged that it can be connected by selector switch to the terminals of any machine at will.

Ammeters. These are also necessary; where the load is reasonably well-balanced the ammeter may be in one phase only of a three-phase machine. Where some small unbalance is expected, the ammeter should be equipped with a selector switch so that it may be connected into each phase in turn. Where, however, appreciable out-of-balance currents are anticipated, there should be an ammeter permanently connected in each phase.

A synchroscope is required where two or more alternators are to be run in parallel and as a standby to this instrument synchronizing lamps should be fitted and the "sequence method" of connection should be employed.

Power factor meter and integrating wattmeters are not essential, but may be considered desirable.

Feeder circuits. The number of feeder circuits leaving the main switchboard is dependent upon the amount of current to be distributed; that is, the size and number of circuit breakers and size and number of cables required depends upon the current load, the greater the current load the more circuits have to be arranged. For 440-volt three-phase a.c. circuits the line current is only 36 per cent of that for equivalent 220-volt d.c. circuits.

TABLE 2—*Current values of main switchboard circuits for 220-volt d.c. and 440-volt a.c. 3 phase*

Service	D.C. 220 volts		A.C. 3-phase 440 volts	
	Connected load, amperes	Estimated maximum load, amperes	Connected load, amperes	Estimated maximum load, amperes
Engine room	2,619	1,934	942	696
Refrigeration	1,571	1,421	565	511
Ventilating fans	260	215	93	77
Deck machinery	2,983	994	1,073	358
Galley	469	383	168	137
Heating	1,003	903	361	325
Lighting	353	297	127	107

Table 2 gives the connected and estimated maximum loads for the various services on an existing ship. It is obvious from columns 2 and 4 that the number and size of circuits can be less for the 440-volt a.c. system than for the 220-volt d.c.

All feeder circuits should be protected by triple-pole circuit breakers, and their category of duty should be such as to be suitable for the maximum short-circuit current which can arise. One is prone to think the most important circuit breaker is the generator or alternator breaker, but as previously shown, a feeder circuit breaker may have far more onerous duties to perform.

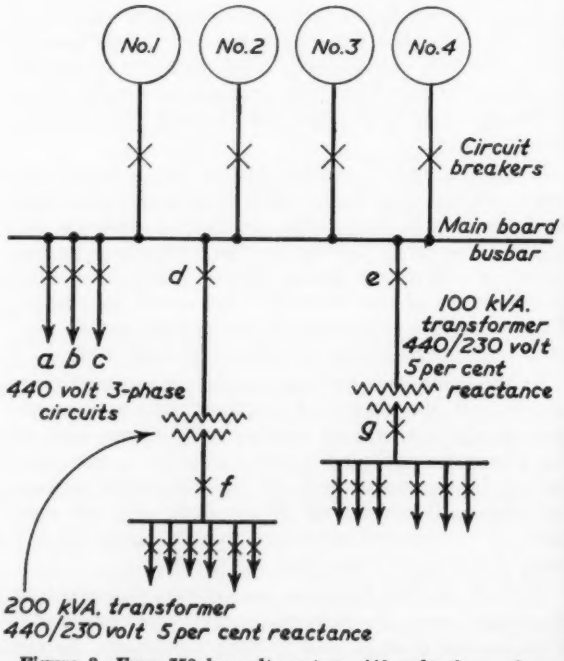


Figure 3—Four 750-kva alternators: 440-volt, three-phase, 10 per cent impedance.

(1) Short circuit capacity at busbars and circuit breakers (a), (b), (c), (d) and (e), 30 mva; short circuit current 39,360 amperes symmetrical.

(2) Short circuit capacities at circuit breakers (f) and (g), 3.53 mva and 1.87 mva respectively.

Short circuit currents at (f) and (g), 8,794 and 4,698 amperes respectively.

The main switchboard being a very vital link in the safety of any modern vessel and also the point of greatest prospective short-circuit current, the fitting of distribution panels and plural or group starting of engine room motors as an extension to the switchboard is greatly deprecated. Such panels and starting equipment should be mounted away from the switchboard. The impedance of the interconnecting cables will then have the effect of reducing the short-circuit current values at the distribution and motor starting panels. At the same time ample space will be available at the main switchboard to ensure maximum clearances and insulation of the switchboard components.

SECTION AND DISTRIBUTION BOARDS

The protection of circuits connected to these boards can be provided by circuit breakers, h.r.c. fuse switches, or where applicable, miniature circuit breakers. Circuit breakers are essential for the protection of three-phase motors against single-phasing where efficient single-phase preventers are not fitted in motor control gear. Where such single-phasing protection is fitted, then the h.r.c. fuse will operate more efficiently than the normal circuit breaker. Miniature circuit breakers have a limited short-circuit capacity and a short-circuit current rupturing capacity of 1 ka. If the short-circuit current exceeds this value at any point of the sytem, then back-up protection must be fitted, which normally is carried out by means of h.r.c. fuses. This does not mean that every circuit breaker should have a fuse behind it; group back-up protection can be arranged. The fuse rating should not be too low otherwise it may blow in a region where the miniature circuit breaker would function satisfactorily; if too high, the fuse may not blow at currents in excess of the capacity of the breaker.

MOTORS

In order to maintain reasonable values of power factor and efficiency, care should be taken to ensure that over-sized motors are not fitted; in other words motor, fan and pump designers should eliminate their margins as far as possible, and it is therefore only logical that motors should be designed for C.M.R. (continuous maximum rating). Except in special cases they should be of the ventilated or deluge proof type and insulated with Class "B" insulation.

All motors for a marine installation can be of the squirrel cage type, and if the above mentioned factors are taken into consideration a motor will result which is low in first cost, efficient in running, low in maintenance cost, simple and robust, and hence inherently reliable.

Standard Squirrel Cage Motor

In this type of motor the squirrel cage winding is designed for minimum practicable losses (low slip) and minimum reactance. Such a machine exerts a comparatively poor starting effort. Reference to Figure 4 shows that at standstill, in the example chosen, a comparatively high value of current is taken from the line. When the motor accelerates this current falls off, as indicated by the current curve. The curve actually shows a maximum line current of 6.3 times full-load value. The torque curve shows that the motor exerts a starting effort of 1.25 times full-load torque which, as the machine gathers speed, rises to over three times full-load value at approximately 80 per cent of full speed.

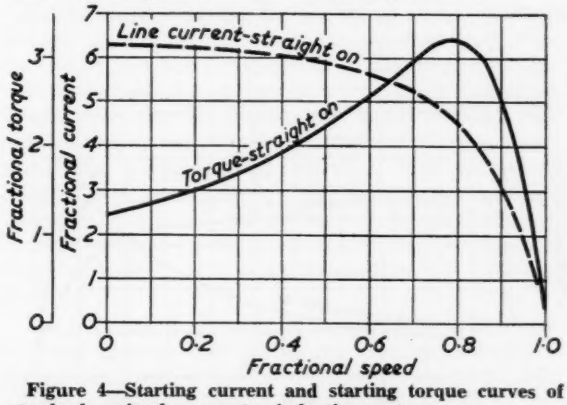


Figure 4—Starting current and starting torque curves of standard squirrel cage rotor induction motor.

Motor: Three-phase 50—400 volts, 50 bhp 1,000/975 rpm—ventilated—B.S.S. 168.

	Efficiency per cent	Power factor	Slip per cent	Amperes
Full load	91.0	0.89	2.5	66.7
Half load	90.2	0.775	1.2	39.7

Special Squirrel Cage Motors

The high-resistance single squirrel cage winding provides a simple means of obtaining increased initial starting torque with a slight reduction of starting current. The disadvantage of such a winding is that the running efficiency of the motor is reduced by the increased resistance of the rotor windings (see Figure 5).

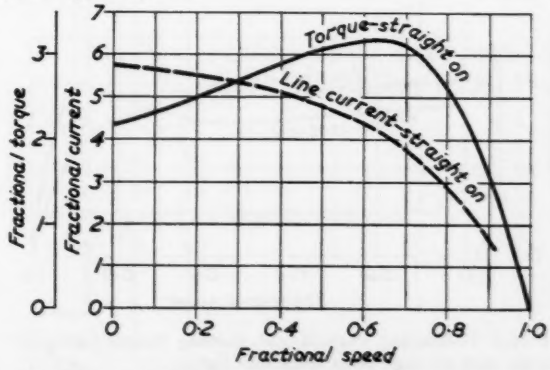


Figure 5—Starting current and starting torque curves of high resistance squirrel cage rotor induction motor.

Motor: Three-phase 50—400 volts, 50 bhp, 1,000/975 rpm—ventilated—B.S.S. 168.

	Efficiency per cent	Power factor	Slip per cent	Amperes
Full load	88.0	0.89	5.6	69.0
Half load	88.7	0.78	2.8	39.0

The high-reactance single squirrel cage winding is usually employed in cases where the main objective is a low starting current with high efficiency, starting torque and power factor being of secondary importance. The increased reactance is introduced by embedding the rotor conductors more deeply in the core and so increasing the magnetic leakage (see Figure 6).

The double squirrel cage rotor combines, in proportions to some extent under control, the advantages of both high-resistance and high-reactance windings. In its usual form the double squirrel cage winding consists of two independent squirrel cages, each with its own separate end ring. One of these windings has a high resistance, and is arranged in the upper portion of the rotor slots, while the other at low resistance, is embedded deeply in the core and therefore has a high reactance. Figure 7 represents an average performance with the rotor designed for an initial starting torque at 1.7 times full-load torque and four times full-load current, when switched direct-on, with an overload capacity of approximately twice full-load torque at about 90 per cent of synchronous speed. The full-load slip and efficiency are practically the same as for the standard squirrel cage motor (Figure 4), but the power factor is about 4 per cent lower.

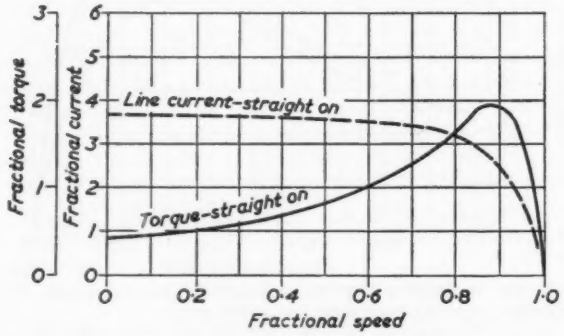


Figure 6—Starting current and starting torque curves of high reactance squirrel cage rotor induction motor.

Motor: Three-phase 50—400 volts, 50 bhp, 1,000/975 rpm—ventilated—B.S.S. 168; straight-on starting.

	Efficiency per cent	Power factor	Slip per cent	Amperes
Full load	90.9	0.86	2.5	69.0
Half load	90.1	0.76	1.2	39.4

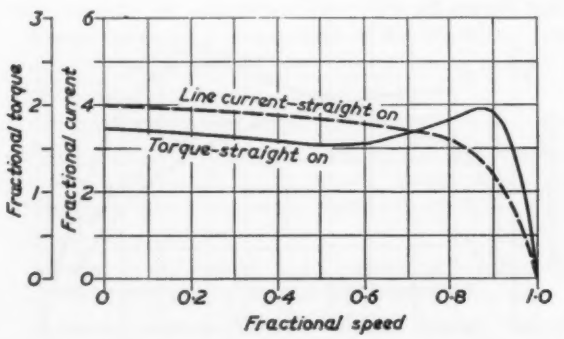


Figure 7—Starting current and starting torque curves of double squirrel cage rotor induction motor.

Motor: Three-phase 50—400 volts, 50 bhp, 1,000/974 rpm—ventilated—B.S.S. 168.

	Efficiency per cent	Power factor	Slip per cent	Amperes
Full load	90.9	0.85	2.55	70.0
Half load	90.1	0.76	1.27	39.4

POWER FACTOR CORRECTION

Power factor correction is an economic proposition for industrial installations but for marine installations such correction would be the exception rather than the rule. The majority of ships are fitted with electric cooking ranges, bakers' ovens, grills, etc., which form a useful basic load of near unity power factor, and which therefore raises the overall power factor of the system. Again, at times of maximum load, motors will in general be operating at their maximum power factor. If the connected load and the load cycle is known, then a near estimate of power factors can be made for the various loads to be expected, and it appears these will lie between 0.835 and 0.87. If the installation is designed for an overall power factor of 0.8 then it is obvious that power factor correction is not required.

CONTROL GEAR

Direct-on starting can be utilized for all motors on board ship, and, basically, any motor can be started by connecting it to the line through a triple-pole switch, but certain protective features are necessary in order to protect the motor. The simplest and most reliable form of direct-on starter is a triple-pole contactor fitted with overload trips on each pole and the contactor operating coil arranged to give the no-volt feature; further, it is desirable to give protection against single-phasing. Figure 8 shows diagrammatically such a motor starter and its simplicity is obvious.

It may be argued that direct-on line starting has two disadvantages:—

(a) The current taken from the line will be five to eight times full-load current with a normal rotor, and this tends to cause dips in the line voltage of the supply system.

It has already been shown that such line currents can be limited to four times full-load current by suitable design of the motor.

(b) High torque and rapid acceleration may be a serious disadvantage. Again, it has been shown that torque and acceleration can also be controlled.

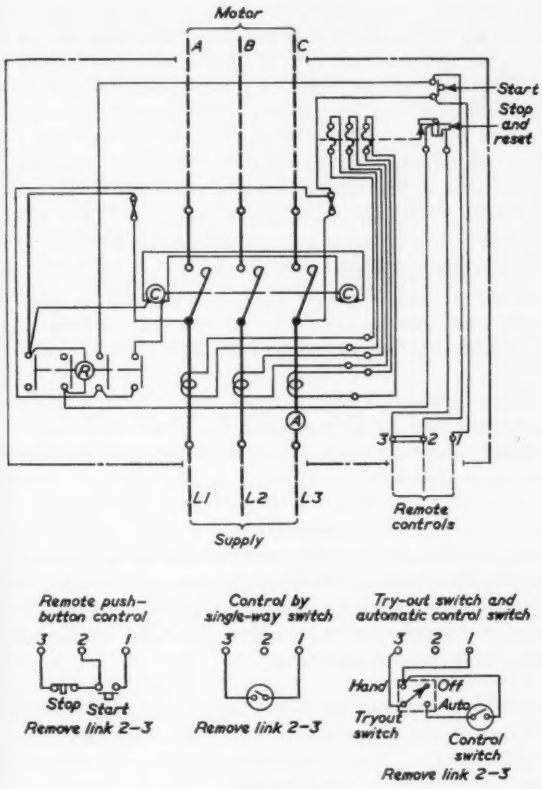


Figure 8

With squirrel cage motors and direct-on starting the motor and control gear manufacturers must work closely together. If such liaison is obtained, then the motor and its starter will be the simplest and most reliable combination one can obtain and, therefore, the cheapest to purchase and maintain.

For certain services such as refrigerating compressors, refrigeration fans, boiler fans, etc., it will be desirable to install two-speed motors, the speeds being "full" and "two-thirds" full speed. These can be direct-on started; the starting current when starting at either speed and the current when changing over from one speed to another can be restricted to a reasonable value and the start or change speed made without shock to the driven machinery.

There are also starters known as star/delta, primary resistor, reactor type and auto-transformer, but normally it is not necessary to consider any of these types for marine work.

The contactor operating coil can function quite satisfactorily from the 440-volt supply, but there are those who propose 110 volts as being more suitable and others who maintain that the coils should operate from a d.c. supply. Such suggestions entail the fitting of transformers and rectifiers, which naturally increase the cost of control gear.

Protection against Single-phasing

"Single-phasing" is caused by an open circuit occurring in one lead while the motor is running. Such an open circuit may occur through a broken lead, badly made joint, blowing of one fuse or failure of switch contact.

On the occurrence of an open circuit in one of the leads to a rotating three-phase motor, it will continue to run as a single-phase motor with an increased current in the other two supply leads. This increased current arises in the following way.

In general terms, the torque developed by an induction motor is proportional to the flux and rotor current. Upon the incidence of a "single-phase" the flux is decreased and, hence, to maintain the same torque and also because of the negative phase sequence torque which is set up, the rotor current and the stator current must increase. This increased current may be sufficient to operate the overload release but this is not always so, and furthermore the current in some of the internal circuits of the motor may increase in a greater ratio than the external leads.

For instance, there may be an appreciable increase in rotor current and while overload releases have sometimes been fitted in the rotor circuit to deal with such a condition, this measure cannot be applied to squirrel cage machines.

In the case of a star connected motor, the increased current taken by the sound phases will pass through the overload releases in the corresponding lines, as shown in Figure 9, and if these overloads are set at a low enough value they will operate and give adequate protection.

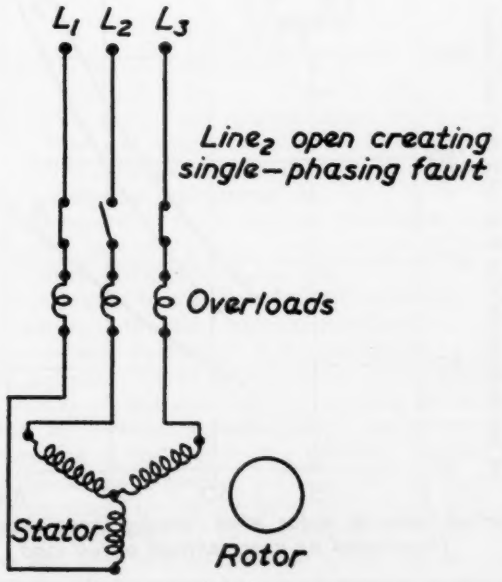


Figure 9—Single-phasing fault on star connected motor.

In the case of delta connected stators, the line currents are the vector sum of two of the phase currents. Under three-phase conditions, the line currents are all equal and are $\sqrt{3}$ times the balanced motor phase currents. A change in load causes the line and motor phase currents to vary almost proportionately. If, however, the current should fail in one supply lead, as shown in Figure 10, the symmetry of the hitherto healthy three-phase circuit no longer obtains, and the motor circuit now consists of two parallel branch circuits, one branch having two motor phase windings, Y and Z, in series, while the other branch consists of the third motor phase winding X.

The curves in Figure 10 show the effect of single-phasing, with L_2 open and the motor running on single phase; the curves indicate in percentages:

A The line current in unbroken lines L_1 and L_3.

B The current in windings Y and Z.

C The current in winding X.

A study of the curves will show that on the opening of one of the supply leads to a delta connected motor, the current divides unequally between the windings of the stator. The increase on one pair of windings is not very great, but the increase in the third winding is very pronounced and is very much greater than the increase of the line current itself.

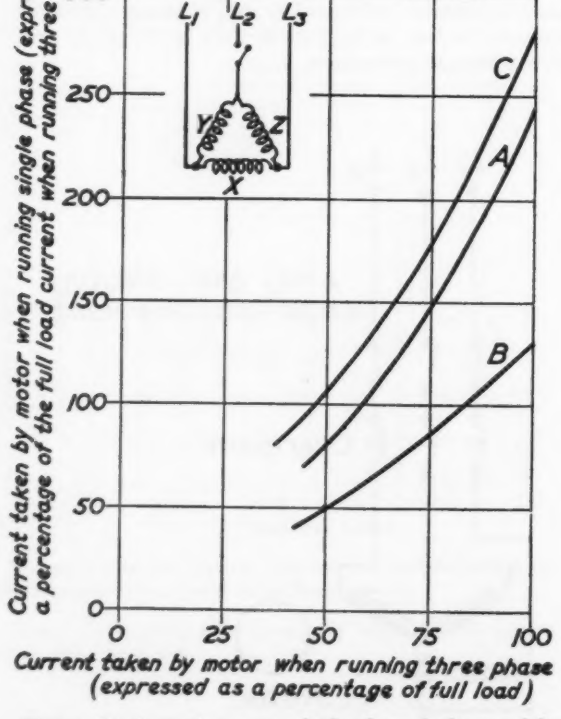


Figure 10—Current curves: single-phase faults on delta connected motor.

For instance, at 75 per cent of full load the opening of one of the supply leads results in the line current rising to 147 per cent of full load and the current in the heavily loaded phase to 180 per cent of the full load value. Thus an overload release designed to prevent the line current exceeding 50 per cent overload will actually permit one of the stator windings of the motor to undergo 80 per cent overload continuously. If the overload is set to trip at 25 per cent overload, it is possible for one phase to carry 50 per cent overload without protection.

If the economic advantages of continuous maximum rated motors are to be reaped it is essential to fit single-phasing protection in the motor control gear.

There are available motor starters in which the manufacturers fit a combined overload and single-phasing preventer as a standard fitment in their control equipment.

LIGHTING

An a.c. installation allows the fitting of fluorescent lighting throughout without the necessity of installing special motor/alternators. Table 3 gives the average lumens for both metal filament single-coil lamps and fluorescent tubes.

TABLE 3—*Comparative Lumens of Metal Filament Lamps and Fluorescent Tubes for Equivalent Wattage*

G.L.S. single-coil 230-volt lamps		Fluorescent tubes		
Lamp, watts	Avg. Lumens	Tube, watts	Type	Avg. Lumens
15	113	15 1½ feet	New Warm White Natural Deluxe Warm White	480 420 330
25	206	20 2 feet	New Warm White Natural Deluxe Warm White	800 640 460
		30 3 feet	New Warm White Natural Deluxe Warm White	1,380 1,170 840
40	330	40 2 feet	New Warm White Natural Deluxe Warm White	1,320 1,080 760
60	584	40 4 feet	New Warm White Daylight Natural Deluxe Warm White Color Matching	2,160 2,040 1,640 1,360 1,600
75	785	80 5 feet	New Warm White Daylight Natural Deluxe Warm White	4,160 3,920 3,120 2,560
100	1,160		Color Matching	3,040

It will be seen from this table that approximately three times the power is required for metal filament as compared with fluorescent lighting for the same intensity of illumination. It follows therefore

that the fuel consumption will be three times as great and in an air-conditioned ship the fuel consumption for air conditioning relative to the lighting load will be in the same proportion. Again, the capital cost of air conditioning plant must be greater where metal filament lighting is installed. In order to demonstrate the effect lighting has on the air conditioning load, an example is quoted.[4] This applies to a saloon.

Total volume of saloon, cu. ft.	40,000
Heat infiltration through structure (including sun radiation), B.t.u./hr.	80,000
Body heat, B.t.u./hr.	40,000
Lighting, etc., B.t.u./hr.	60,000
Fan heat, B.t.u./hr.	20,000
Total heat gain, B.t.u./hr.	200,000

If the lighting B.t.u./hr. is reduced from 60,000 to 20,000 by installing fluorescent lighting, the total heat gain becomes 160,000 B.t.u./hr., a reduction of 20 per cent. For a certain type of 18,000-ton vessel the total heat gain has been given as 6,000,000 B.t.u./hr. and such a ship would have some 300 kw of metal filament lighting load, which is the equivalent of 1,023,000 B.t.u./hr. If a diversity factor of 0.8 is taken for the lighting load, then the effective heat input is 818,400 B.t.u./hr. If a factor of one-third is taken for flourescent lighting as compared with metal filament, then the heat input due to lighting becomes 272,800 B.t.u./hr., a reduction of 545,600 B.t.u./hr. or some 9 per cent of the total heat input. It is obvious therefore that the first cost for the air conditioning plant must be less. The question of fuel consumption for lighting must also be considered, and fuel consumption for air conditioning relative to the lighting load. If the metal filament lighting load is taken as 300 kw for an 18,000/20,000-ton vessel, then Table 4 shows the relative fuel consumptions.

TABLE 4—*Comparison of fuel consumption for metal filament lighting and fluorescent lighting and for air conditioning relative to lighting*

Lighting load, kw's.		lb./hr. at 0.6 lb./kw/hr. Fuel consumption	
M.F.	Fluorescent	M.F.	Fluorescent
300	100	180	60
Lb./hr. for air conditioning at 80 per cent efficiency		225	75
Total fuel consumption, lb./hr.		405	135

If it is assumed that 60 per cent of the lights are switched on twelve hours per day, which incidentally is not unreasonable for marine installations, and take Diesel fuel at £10 per ton, this means a daily saving of

$$\left(\frac{405\times12\times0.6\times10}{2{,}240}\right)-\left(\frac{135\times12\times0.6\times10}{2{,}240}\right)=£8.7$$

or a yearly saving of some £3,220.

It does appear, therefore, that the capacity of the air conditioning plant can be reduced by 9 per cent plus an annual saving of fuel cost of £3,220.

DECK MACHINERY

This subject has already been ably dealt with in a previous Institute paper.[5] The author would suggest, however, that closer attention should be given to fitting winches suitable to the duty cycle of the ship in question. Table 5 shows the somewhat haphazard fitting of winches in existing ships of a company's fleet.

TABLE 5—*Motor h.p. required for various winch ratings*

Ton lift	Ft./min.	Motor h.p.
3	80	23
3	100	26
3	130	34
5	65	30
5	80	31
5	100	43
5	130	55

If it is necessary to fit 3-ton winches at 130ft./min., then obviously 3-ton winches at 80ft./min. are too slow, yet these latter winches have given twenty-five years' satisfactory service and maintenance has been less for the simple reason that the control gear is far less complicated. Similar remarks apply to the 5-ton winches at 65ft./min., and the vessel in which they are fitted can lift 10,000 tons of general cargo. Observations have been made of the weights lifted and the rate of working and for new construction which the author has in mind it has been decided that single-speed squirrel cage motor winches for lifting 3 tons at 100ft./min. will be quite suitable.

COSTS

Certain items of equipment in an a.c. installation will cost more than for d.c., others considerably less. The saving in first cost depends upon two factors:—

(*a*) Size and type of vessel.

(*b*) The attitude and exertions of the shipowners' technical representatives.

With regard to the first point, the larger the installation and the greater the number of motors fitted, then the greater the saving.

With regard to the second point, it should not be left simply to the shipbuilder to purchase and install the necessary equipment. It is essential that a qualified and experienced representative of the shipowner should get out and about, witnessing demonstrations of various manufacturers' equipment and examining it until he is in a position to select the equipment he considers suitable for his purpose. Having made his choice he should stand firm and not allow himself to be persuaded to modify this, and add that, and so find that what was an excellent piece of equipment for his purpose has now become "marine" equipment.

TABLE 6—*Comparative Cost of Cables*

	220-volt d.c. P.C.P.—V.I.R.			440-volt 3-phase a.c. P.C.P.—V.I.R. 3-core			440-volt 3-phase a.c. P.C.P. Butyl 3-core		
kW.	Cable size	Length, yd.	Cost, £	Cable size	Length, yd.	Cost, £	Cable size	Length, yd.	Cost, £
10	7/.064	200	33	7/.036	100	33	7/.036	100	33
25	19/.083	200	122	19/.052	100	86	7/.052	100	49
50	37/.103	200	308	19/.083	100	180	19/.064	100	121
75	61/.103	200	507	37/.083	100	314	19/.083	100	179
100	91/.103	200	712	37/.103	100	435	37/.083	100	313
150	61/.103	400	1,014	37/.083	200	628	37/.103	100	435
200	91/.103	400	1,424	37/.103	200	870	37/.083	200	626
300	91/.103	600	2,136	61/.103	200	1,448	37/.103	200	870
400	127/.103	600	2,842	37/.103	400	1,740	37/.093	300	1,137
Total cost			9,098			5,734			£3,763
Percentage cost			100			63			41

TABLE 7—*Comparative Weight of Copper in Cables*

	220-volt, d.c. system P.C.P.—V.I.R.			440-volt 3-phase a.c. system P.C.P.—V.I.R. 3-core			440-volt 3-phase a.c. system P.C.P.—Butyl 3-core		
kW.	Cable size	Length, yd.	Weight, lb.	Cable size	Length, yd.	Weight, lb.	Cable size	Length, yd.	Weight, lb.
10	7/.064	200	53	7/.036	100	25	7/.036	100	25
25	19/.083	200	242	19/.052	100	142	7/.052	100	52
50	37/.103	200	727	19/.083	100	363	19/.064	100	216
75	61/.103	200	1.199	37/.083	100	708	19/.083	100	363
100	91/.103	200	1,788	37/.103	100	1,090	37/.083	100	708
150	61/.103	400	2.398	37/.083	200	1,416	37/.103	100	1,090
200	91/.103	400	3.576	37/.103	200	2.180	37/.083	200	1,416
300	91/.103	600	5.364	61/.103	200	3.596	37/.103	200	2,180
400	127/.103	600	7.488	37/.103	400	4,360	37/.093	300	2,667
Total weight			22,835			13,880			8,717
Percentage weight			100			60			38

The next step to take is to compile a detailed and water-tight specification.

It is impossible in a paper of this description to give detailed costs; furthermore such costs will vary from ship to ship, but an indication of the economies which can be made and the reduction in weight and volume of equipment is given.

Cables

In order to obtain a fairly reasonable figure for cable cost, the author took for an example a 17,000-ton passenger cargo liner which had a 220-volt d.c. installation and a generating capacity of 2,100 kw and converted it into a 440-volt three-phase system, the cable in each case being of P.C.P.-sheathed V.I.R. type, single core for the d.c. system and three core for the a.c. It was found that a saving of some 30 per cent could be achieved.

A new type of rubber insulation, known as "Butyl," is now coming on to the market, and Table 6 gives an indication of the economy which can be effected by the adoption of a 440-volt a.c. system and the still further economy by the use of "Butyl" rubber insulated cables. The figures given are for transmitting various values of power a distance of 100 yards. It will be seen from this table that a saving of some 37 per cent in cost can be achieved by the adoption of a 440-volt system, and a further 22 per cent by the installing of "Butyl" rubber insulated cables. The saving in weight of copper installed is indicated in Table 7.

Motors and Generators

A study shows the appreciable saving in volume, weight and cost of the a.c. machine as compared with the d.c.

An appreciable economy can be effected where turbo-generators are installed. For the larger capacity generators 750 r.p.m. appears to be the limit for 220-volt d.c. machines, whereas for the a.c. generator of similar capacity the r.p.m. can be more than doubled, that is, 1,800 r.p.m., and the saving in cost amounts to some 40 per cent, which is quite an

appreciable sum when considering generators of 1,200 and 1,500 kw capacity.

Control Gear

Figures 11 to 14 show the relative costs of d.c. and a.c. control gear. Constant speed d.c. is compared with single-speed a.c. and variable speed d.c. with two-speed a.c. Up to 80 h.p. d.c. the controllers are of the ratchet step-by-step type complete with isolator and ammeter, and above 80 h.p. they are of the automatic contactor type. Every endeavor has been

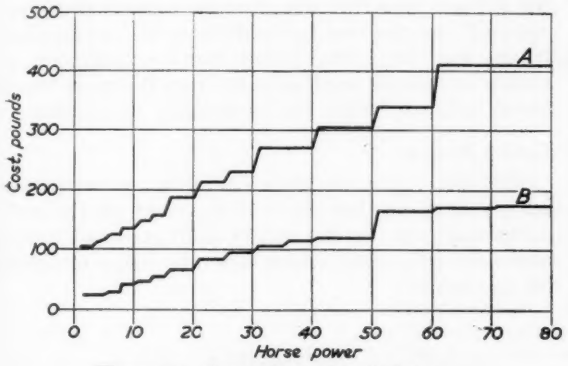


Figure 11—Comparison of costs between:

A—220-volt direct current cam operated starters for constant speed motors.

B—440-volt alternating current direct-on starters with single-phasing preventers, 1-80 h.p.

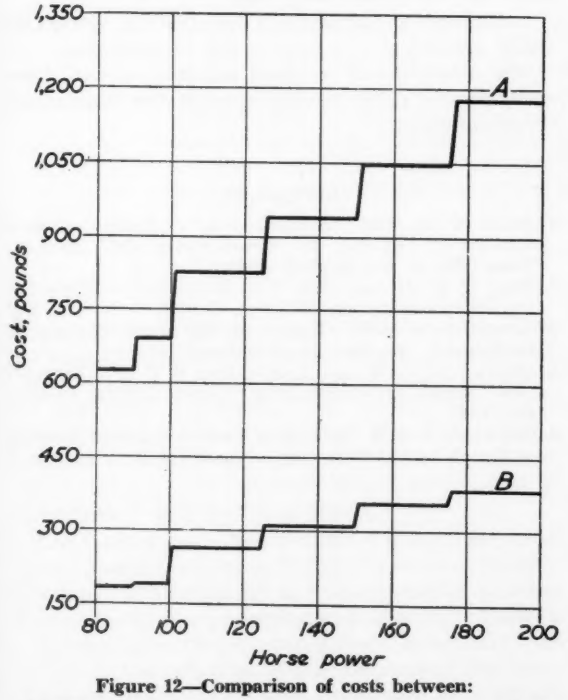


Figure 12—Comparison of costs between:

A—220-volt direct current automatic contactor panels for constant speed motors.

B—440-volt alternating current direct-on starters with single-phasing preventers, 81-200 h.p.

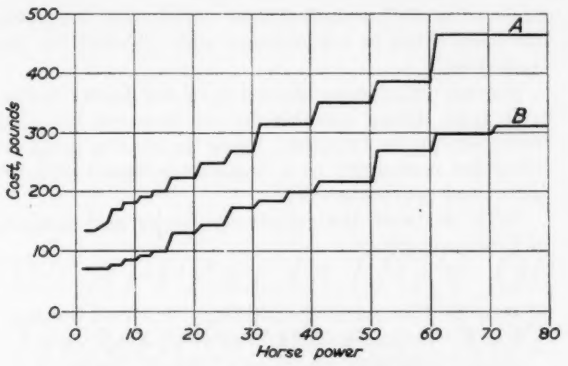


Figure 13—Comparison of costs between:

A—220-volt direct current cam operated starters for variable speed motors.

B—440-volt alternating current two-speed direct-on starters with two sets of overloads (and single-phasing preventers), 1-80 h.p.

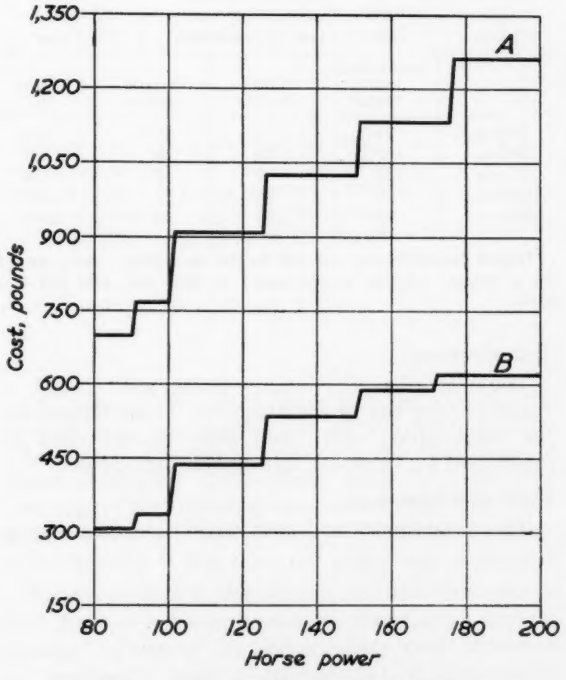


Figure 14—Comparison of costs between:

A—220-volt direct current automatic contactor panels for variable speed motors.

B—440-volt alternating current direct-on two-speed starters with two sets of overload and single-phasing preventers, 81-200 h.p.

made to quote for control gear which over the years has been fitted in conjunction with 220-volt d.c. installations.

The a.c. equipment quoted is of the heavy industrial type, being suitable in all respects for ship work, the prefix "marine" being omitted in order to bring the cost down to a reasonable figure without sacrificing performance.

Table 8 shows the relative volumes and weights of such equipment.

TABLE 8—*Comparative weights (lb.) and cubage (cu. ft.) for 220-volt d.c. and 440-volt a.c. motor starters: constant speed—d.c.; single speed—a.c.*

H.P.	220-volt d.c.		H.P.	440-volt a.c	
	Weight	Cu.Ft.		Weight	Cu.Ft.
1-12.5	110	9.0	1-7.5	26	1.5
—	—	—	8-15	48	2.5
13-25	210	14.0	16-25	61	4.0
26-50	432	23.0	26-50	64	6.5
51-80	562	32.0	51-80	114	7.5

TABLE 9—*Cost, dimensions and weight of single-phase, air cooled transformers*

25 kva	£116	Class A insulation	50° C rise
50 kva	£188	Class A insulation	50° C rise
75 kva	£250	Class A insulation	50° C rise
100 kva	£290	Class B insulation	75° C rise
150 kva	£345	Class B insulation	75° C rise

	Approximate length, inches	Width, inches	Height, inches	Weight, lb.
25 kva	24½	18	34½	500
50 kva	30½	20	48	920
75 kva	35	24	56	1,350
100 kva	36	26	57	1,900
150 kva	42	57	63	2,500

Owing to the heavy current in the secondary, there would be a copper busbar arrangement on the 100- and 150-kva sizes.

Transformers

Table 9 gives the cost, volume and weight of various capacities of transformers. These figures are for single-phase units, and such figures must be multiplied by three for three-phase equipment.

Deck Machinery

This equipment will cost more than d.c. equipment; how much more depends on how closely the shipowner wishes to emulate d.c. performance. Suitable deck machinery can be provided and, incidentally, is being fitted, at a reasonable cost, bearing in mind the overall economy which can be achieved with an a.c. installation. It is the general opinion that a fall in cost of this machinery will take place when production is really underway.

Main Switchboards

This is another item which will be more expensive for a.c. than for d.c., but by careful planning, not only can the cost be held down to a reasonable figure, but the safety factor can be improved; to supply numerous small circuits from the main board is not only expensive but potentially dangerous.

Galley Ranges

The main galley ranges will also be greater in cost for a.c. than d.c., but this will be offset, particularly in the long run, by the ability to fit standard pieces of hotel equipment which are primarily designed for a.c. supply.

CONCLUSIONS

The overall cost of an a.c. 440-volt three-phase installation is less than its equivalent 220-volt d.c. system for the passenger and passenger/cargo type of vessel. It is also perfectly obvious that maintenance costs will be considerably less.

In a properly planned and installed a.c. system the safety and reliability factors will be improved.

The achievement of these advantages will, however, depend upon the initiative of the shipowners' representatives.

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J. H. POTTER

A NEW APPRECIATION OF THE MEMOIR OF CARNOT

THE AUTHOR

was born in the City of New York and was educated in engineering at Columbia and at the Johns Hopkins University. In addition to five years in the chemical and shipbuilding fields, he has had seventeen years of experience in research and teaching at the University level. He has filled academic assignments at Johns Hopkins University, the University of Illinois, and the Stevens Institute of Technology. Since 1955 he has been Dean of Graduate Studies at the latter institution. He has been a member of the A.S.N.E. since 1939 and has contributed several other papers to the JOURNAL.

SUMMARY

In the English translations of the original memoir of Carnot the words "feu," "chaleur" and "calorique" were each considered as equivalent to "heat." Brønsted and La Mer claim that "calorique" may have been intended as the property we now identify as "entropy." To date there has been no engineering study of the consequences of the new interpretation of Carnot's "calorique." An analysis is offered to show the effects of this substitution in the memoir.

INTRODUCTION

PERHAPS THE greatest individual contributor to the science of thermodynamics was Carnot. He left only his single paper on the motive power of heat,[1] yet this and his posthumous notes[2] contain a wealth of information and ideas. The Carnot paper attracted very little attention at the time it was published, but was later discovered and interpreted by Clapeyron,[3] Kelvin[4] and others.

The Carnot cycle has remained one of the great classic foundation stones in the structure of thermodynamics, and continues to find application in many diverse fields of engineering and science.[5] While it is inconceivable that anything could be added to the stature of Carnot, it is equally important that none of the credit for his inspired prescience be withheld. It is generally conceded that he originated the idea of the reversible cyclic process and that he is credited with the Second Law of Thermodynamics. However, some of his critics have claimed that, in the development and application of his Principle, he overlooked or failed to recognize the First Law of Thermodynamics. Still others have held that the "calorique" mentioned in the memoir tied that work to the outmoded caloric theory of heat, and had no new meaning at the time the paper was composed.

Recent reports in the physics journals have shown that there is a strong possibility that Carnot had intended "calorique" as the property now identified as "entropy." Such a substitution, if admissable, brings to light a new interpretation of the Carnot cycle, and shows that there was no violation of the First Law of Thermodynamics in the development of the cycle.

This paper reports upon a literature search into the problems outlined above, and presents some of

the consequences arising when "calorique" is translated as "entropy."

NOMENCLATURE*

The following symbols are used in the body of the paper:

c = constant
d = exact differential
đ = inexact differential
H = height
J = mechanical equivalent of heat
L = depth
P = pressure
Q = heat
q = heat
R = gas constant
S = entropy
T = temperature, absolute
V = volume
w = width
W = work

THEORY

In the English versions of the original paper, both Magie[6] and Thurston[7] interpreted the words "feu," "chaleur" and "calorique" indiscriminately as heat. This led to considerable difficulty in understanding some of the physical ideas in the paper, but was generally explained in terms of the fact that Carnot had written in the idiom of the caloric theory of heat rather than the kinetic theory. In the Thurston translation "calorique" was given as caloric.

Carnot expressed his Principle in italics. His statement linked "chaleur," in the general sense of thermal energy, to a transported property identified as "calorique."

> The motive power of heat is independent of the agents employed to realize it; its quantity is fixed solely by the temperatures of the bodies between which is effected, finally, the transfer of the caloric. (Appendix—(a)).

Carnot's reference to work, accomplished in a cyclic operation was given as:

> Wherever there exists a difference of temperature, wherever it has been possible for the equilibrium of the caloric to be reestablished, it is possible to have also the production of impelling power. (Appendix—(b)).

"Feu," although literally "fire," has been translated as heat, with the implication of heat from a high temperature source. "Chaleur" translates easily as heat in the usual sense. The term "calorique" has been the key word in the understanding of the memoir, although many able men failed to recognize the new principle that it implied. Even Ostwald[8] interpreted "Calorique" in terms of the earlier theory of heat, although he noted that Carnot had indicated an essential difference between "chaleur" and "calorique."

The new understanding of Carnot's work dates from 1911 when Callendar,[9] in a masterful paper, presented parallel analyses of the memoir, showing it to be consistent for either the kinetic or caloric theories of heat. Callendar showed that the "chute de calorique" corresponded to the transport of entropy, although Carnot had been most explicit in his own statement:

> The production of motive power is then due in steam-engines not to be an actual consumption of caloric, but TO ITS TRANSPORTATION FROM A WARM BODY TO A COLD BODY . . . (Appendix (c)).

Callendar also emphasized the fact that entropy, considered as the work done in a Carnot cycle per degree difference in temperature, was more comprehensible than the customary definition:

$$dS = \left(\frac{đQ}{T}\right)_{rev.}$$

A similar approach was used by Lunn[10] who showed that whether heat or entropy was conserved in a system depended upon the interpretation of "calorique." The argument he employed is illustrated by the diagram in Fig. 1.

Two possible paths are suggested for the flow of heat between two reservoirs, A and B, the former being the source. The path at the left indicates the direct flow of heat, with đQ leaving the source and the same đQ entering the sink. The path on the right involves passage through a reversible engine which produces work đW, and rejects heat đq, to the sink. For the second path it is apparent that less heat will enter the sink, even though the same amount of heat is withdrawn from the source.

As the source temperature, T_1, and the heat withdrawn đQ, is the same for either path, the initial entropy must be the same. However, at the sink end, đQ is greater than đq, and as the sink tem-

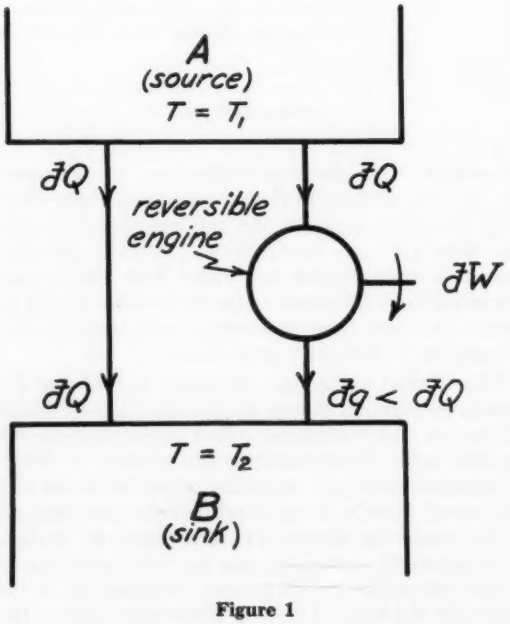

Figure 1

* Passages taken from the memoir are quoted from the Thurston translation. In each case, the original French text has been given in the Appendix, identified by the lower case letters.

perature T_2 is the same, the entropy will be greater at the end of the direct path than through the reversible engine. As a reversible adiabatic expansion was specified:

$$\frac{\partial Q}{T_1} = \frac{\partial q}{T_2} \quad \text{and} \quad \frac{\partial Q}{T_2} > \frac{\partial Q}{T_1}$$

Lunn held that if "calorique" was interpreted as heat, it was conserved along the direct path between the reservoirs, whereas "calorique" interpreted as entropy was conserved in the path through the reversible engine.

Interest in the re-interpretation of the Carnot paper did not develop immediately after the Callendar and Lunn articles. The next writer to take up the problem was Brønsted.[11] Unfortunately his paper was written in Danish, and might have gone unnoticed but for the interest of one of his early collaborators, V. K. La Mer. He in turn read a paper which appeared originally as a note[12] and was later published in full.[14] La Mer preferred to translate "feu" as flame or fire, and not as heat. He accepted "chaleur" as heat, but stressed that entropy was the meaning of "calorique." In this he was supported by Brillouin.[13] In a later paper[15] La Mer presented a searching analysis of the work of Carnot, and established a strong case for "calorique" as the quantity conserved in a reversible cycle. He was disputed by one critic[16] but supported by another.[17]

To show how meaningful this apparently innocuous substitution can be, several items in the memoir are analyzed below:

Steam Engine

There is evidence that Carnot, as an engineer, worked from the specific to the general in the development of his ideas. He cautioned that heat engines should be considered in the broadest sense possible, yet he started his analysis with a steam engine.

In Fig. 2 a cycle is shown in the P-V plane for a steam engine such as might have been available in the days of Carnot. The saturation loci have been exaggerated in order to present a more graphic case, and the point, b, representing the steam as it enters the cylinder, has been taken in the wet region.

Carnot imagines the isothermal paths a-b, and c-d, to be traced while the working fluid is in contact with a heat reservoir A, and a sink B. respectively. He indicates an understanding of our modern notions on the flow of heat, for he asks himself how heat can actually be imparted during an isothermal operation. He answers this by using saturated steam and ice as the source and sink respectively, and specifying that infinitesimal temperature differences be permitted between the working fluid and the appropriate reservoir.

For the non-isothermal paths his statements, at this part of the memoir, are less clear. Actually, having specified neither adiabatic nor reversible conditions, his analysis is made valid only by the fact that he has required that the "calorique" be conserved, and the interpretation of this word as entropy becomes necessary. For the expansion, b-c, he merely asks that the temperature be spontaneously reduced during the expansion and that it terminate at the sink temperature. The compression along d-a, gives him considerable difficulty. He finally offers alternate solutions; either the difference between source and sink temperatures shall be only a very small dT, or the novel concept is offered that a graduated series of thermal reservoirs be interposed along the compression path so that heat is exchanged only across a temperature differential dT in any one step.

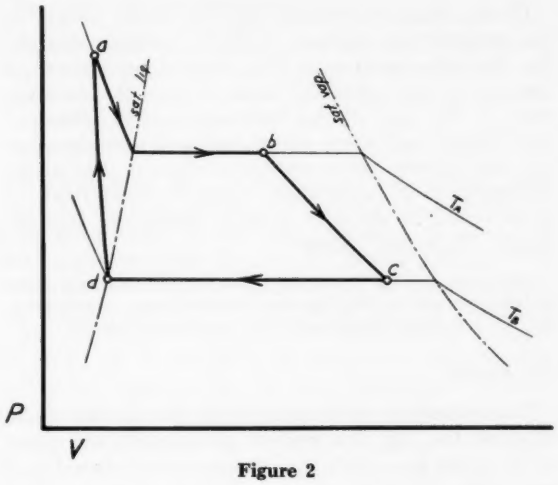

Figure 2

A most important contribution comes to light in this part of the paper, for Carnot points out that the heat addition could have been made at the lower temperature, with an input of work and a heat rejection at the upper temperature. This, then, would appear to be the earliest suggestion of mechanical refrigeration.

Reversibility is clearly specified by Carnot who asks that "calorique" (entropy) be imparted only during the isothermal steps, and that there be neither loss of motive power nor entropy in the other parts of the cycle. Hence, the exact inverse of the cycle completely restores the "calorique" for the exact work input that was produced in the forward cycle:

$$\oint_{abcd} dS = 0 = \oint_{dcba} dS$$

$$\oint_{abcd} \partial W = - \oint_{dcba} \partial W$$

As each reversal exactly restores the starting condition, an indefinite number of alternative operations could be carried out without producing any net work or any increase in entropy.

Carnot cautions, repeatedly, that there should be no temperature changes without volume changes, for the latter overcome the external resistances of the system and produce work. It was the assumption, on the part of the translators, that "chaleur" and "calorique" were equivalent and interchangeable, that caused some writers to assume that in the conservation of "calorique," taken to mean heat, no work could be done in a cyclic operation. For example, Thurston[7] states:

> Carnot was in error in assuming no loss of heat in a completed cycle and in thus ignoring the permanent transformation of a definite proportion into mechanical energy . . .

Air Engine

The customary presentation of the Carnot cycle involves the use of a perfect gas, usually air taken as an ideal gas, with the alternate isothermal and reversible adiabatic steps in a single cylinder. This is illustrated in Fig. 3, in which the original notation is used.

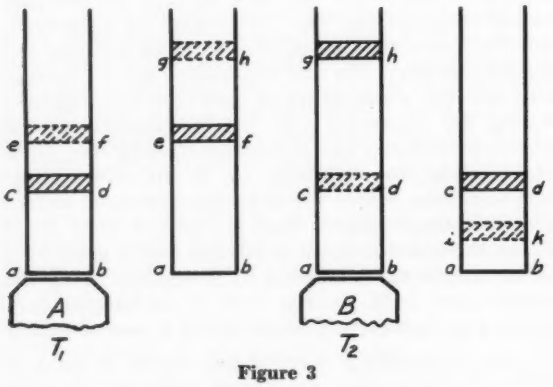

Figure 3

The cylinder in contact with the hot body A takes on "calorique" as the volume increases as shown by the displacement of the piston, the operation being isothermal. The piston and cylinder then become perfect insulators; the adiabatic expansion then carries the piston to the maximum volume. The assembly is then placed in contact with the sink B and the air is compressed at the lower temperature T_2, with a consequent loss of "calorique." Compression along a reversible adiabatic restores the working fluid to the initial conditions. It is to be noted that in this cycle there is a consumption of heat and a production of work. Entropy, not heat, is the quantity conserved.

The P-V representation of the cycle is shown in Fig. 4, and the T-S plane is shown in Fig. 5. In each case the work in the cycle is shown shaded. Between any two temperature limits the only way to increase the work output is to increase the volume change at the upper temperature. Thus, extending the isothermal heat addition from b to b′ would produce more work; from b′ to b″ the work could be

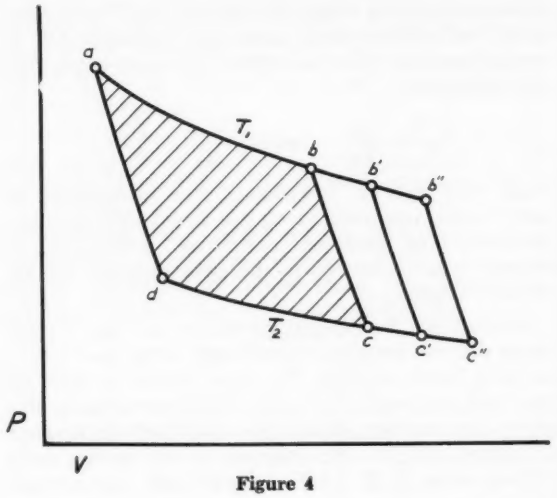

Figure 4

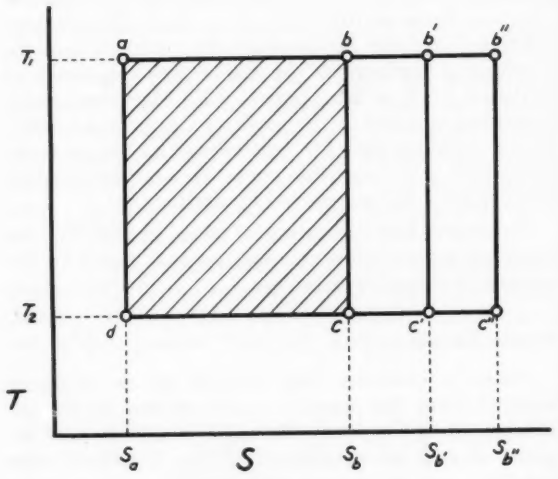

Figure 5

still further increased. Carnot realized this and pointed out that the need for high pressures stemmed from the need to obtain greater isothermal volume changes. He knew of the compound engine, and even predicted that steam engines would someday use more than two expanding cylinders.

Mechanical Analogy

At the beginning of the nineteenth century the science of applied mechanics was highly developed. Carnot voiced the hope that a similar development would take place in the field of heat, and his memoir was a first step in this direction. As a further evidence that he meant something new by "calorique," he cited the mechanical analogy of the waterfall.

The work that may be performed by a waterfall

is found from the product of the difference in elevation and the quantity of water flowing. The work produced by a Carnot engine depends upon the product of the difference in temperature and the "chute de calorique", in other words upon the product of the temperature change and the entropy change. The additional work increments obtainable by extending the isothermal heat addition in Fig. 5 is therefore analogous to the work increments obtainable by extending the width of a waterfall, w, of constant depth, L, and height, H, as shown in Fig. 6.

Where there are limits on expansion, the work in a cycle having a fixed source temperature can be increased only by lowering the temperature of the sink. This is shown graphically in Fig. 7, where for a given entropy change, dS, the work increment d-c-c'-d' becomes available by reducing the sink temperature from T_2 to T_3. Carnot emphasized that heat should always be absorbed at the highest possible temperature and rejected at the lowest temperature provided by the environment.

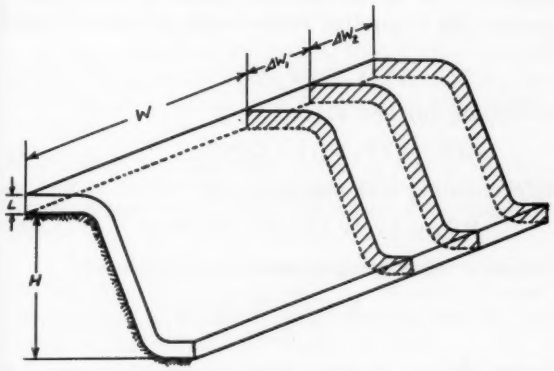

Figure 6

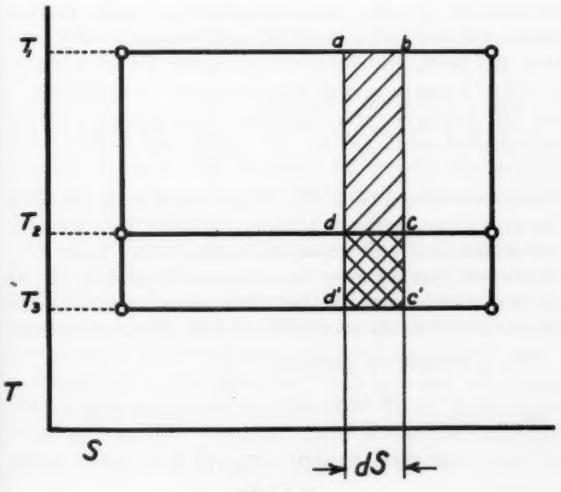

Figure 7

Clapeyron Interpretation

It has been mentioned that Clapeyron discovered the Carnot paper and brought it to the attention of the world at large. In Clapeyron's analysis of 1834 he published the first P-V diagram for the Carnot cycle. However, he also misinterpreted "calorique."

Referring to Fig. 3, Clapeyron noted that heat must be absorbed during the contact of the cylinder with the source A, and that heat must be rejected during contact with the sink B. However, he did not understand that the entropy should be restored during the contact with B. Instead he specified that the same amount of heat imparted by the source A must be given up to the Sink B. This was undoubtedly one of the reasons that Kelvin, Clausius and Thurston thought that no work was done in the cycle.

The error introduced by Clapeyron is illustrated by the diagram in Fig. 8. Here isothermal heat absorption takes place along a-b, in an amount represented by the area shown partially shaded. Reversible adiabatic expansion takes place between b and c. For the working fluid to reject heat at T_2 in equal amount to that originally supplied, the entropy would have to be reduced from c to d, so that the area under a-b would be exactly balanced by the area under c-d. It is then impossible to return from d to a along a reversible adiabatic path, so that a Carnot cycle cannot be realized. However, balancing the "calorique" during the contact of the working fluid with the sink B enables one to complete a Carnot cycle.

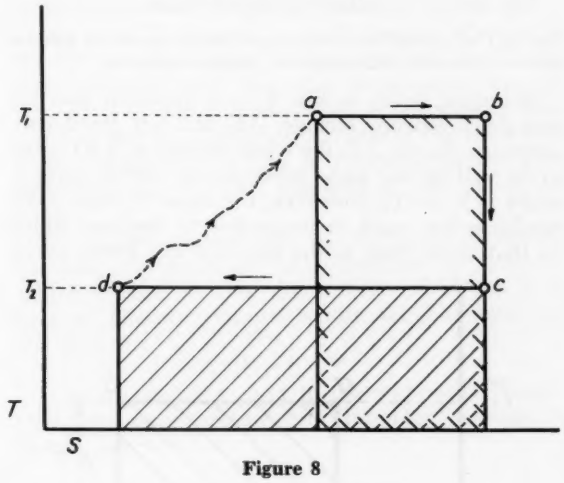

Figure 8

One of the baffling demonstrations offered by Carnot has been his wording of the operations presented in Fig. 3. In the Thurston translation, the first two steps involve addition of "heat" in an amount "a" along the upper isothermal, and "heat" "b" along the compression path. Likewise, the "heat" rejected along the lower isothermal is "b'";

that in the expansion step is "a'." Carnot then claims that:

$$a + b = a' + b'$$

in which case no work could be done. If on the other hand, entropy is the variable quantity:

$$a + 0 = 0 + b'$$

and the conservation of the "calorique" has been effected, and work has been done.

Two interesting corollaries of the Principle of Carnot derive from his considerations on the properties of gases. The first is that for a given isothermal volume increment, more heat is required to maintain isothermal conditions at high temperatures than at lower temperatures. This is shown in Fig. 9, where the volume change from a to b at the temperature T_1 involves the heat represented by the area a-b-i-j. The same volume change at the lower temperature T_2, involve only the heat represented by the area e-f-i-j.

The second corollary is less obvious:

The fall of caloric produces more motive power at inferior than at superior temperatures. (Appendix—(d)).

Referring again to Fig. 9, it is apparent that for any given entropy change, $\triangle S$, and any given temperature change $\triangle T$, the work produced in a Carnot cycle will be the same whether the initial temperature is T_1 or T_2. However, the upper Carnot cycle produces less work in proportion to the heat added to that cycle than is the case for the lower cycle.

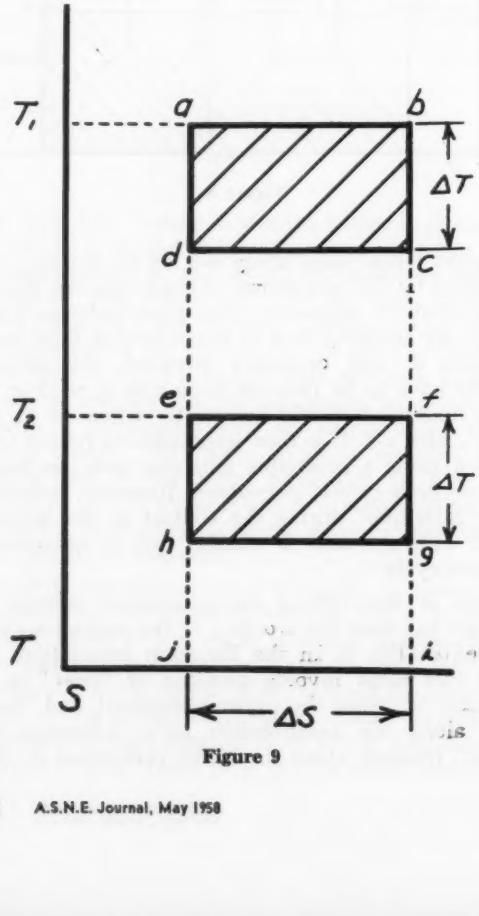

Figure 9

This is perhaps a reasonable interpretation for a rather cryptic statement.

Mechanical Equivalent of Heat

It has been noted previously that Carnot appreciated the implications of the First Law of Thermodynamics if the entropy interpretation of "calorique" is admissable. Furthermore he specifically states the conservation principle in his notes.*

Carnot also attempted to establish the mechanical equivalent of heat as a consequence of his Principle. Callendar has supplied the algebra which was only described in the original text. For a cyclic process between (t)°C and (0)°C, the relation of heat and work is given by:

$$W/Q = F(t) \quad \ldots\ldots (1)$$

where $F(t)$ is a function of the temperature limits of the cycle. Restricting the temperature range to (dT), with a finite heat addition, Q,

$$(\partial W) \;/\; (dT) = (Q)\, F'(t) \quad \ldots\ldots (2)$$

where $F'(t)$ is the derived value of $F(t)$. For a perfect gas expanding isothermally between V_1 and V_2:

$$W = RT\,(\mathrm{Log}_e\,(V_2/V_1)) \quad \ldots\ldots (3)$$

combining (3) and (1):

$$RT(\mathrm{Log}_e\,(V_2/V_1)) = Q\,F(t) \quad \ldots\ldots (4)$$

differentiating with respect to (t):

$$R(\mathrm{Log}_e\,(V_2/V_1))\;(dT) = Q\,F'(t) \quad \ldots\ldots (5)$$

and for a fall of temperature of one degree:

$$Q = \frac{R\,(\mathrm{Log}_e\,(V_2/V_1))}{F'(t)} \quad \ldots\ldots (6)$$

Carnot claimed that equation (6) would be true for all gases. This requires, however: (a) Molal quantities, or at least partial molal quantities in constant proportion, (b) the same temperature scale, (c) the same volume ratio, and (d) adherence to the perfect gas laws. Substituting (3) and (6) in (1):

$$\frac{W}{Q} = \left\{\frac{RT(\mathrm{Log}_e\,(V_2/V_1))}{\dfrac{R(\mathrm{Log}_e\,(V_2/V_1))}{F'(t)}}\right\} = (T)\,F'(t) \quad \ldots\ldots (7)$$

Carnot reasoned that $(T)\,F'(t)$ must be a constant for any given isothermal heat addition. This we now recognize as the mechanical equivalent of heat, (J). However, Carnot was less successful in his efforts to prove this due to the inaccurate values of the physical constants available to him. Recapitulating:

For a reversible process:

$$W/Q = (J) \quad \ldots\ldots (8)$$

For a Carnot cycle:

$$W/Q = (J)\,(T_1 - T_2)/(T_1) \quad \ldots\ldots (9)$$

* See Appendix (e).

Carnot did have knowledge of the earlier experiments of Rumford[18] and Davy[19] which indicated that heat was related to motion. In his notebook he outlined experiments to determine the mechanical equivalent of heat, and even made some rough computations which are not too far from modern values. However, the definitive experiment was made much later by Joule.[20]

DISCUSSION

The entire memoir of Carnot undergoes startling transformations if the entropy interpretation of his "calorique" is accepted. It is not fully clear that this is possible, as Carnot left at least one very cryptic statement on this point:

> It is considered unnecessary to explain here what is quantity of caloric or quantity of heat (for we employ these two expressions indifferently), or to describe how we measure these quantities by the calorimeter. (Appendix—(f)).

La Mer[15] has interpreted this controversial statement to mean that the interchangeability of "chaleur" and "calorique" at constant temperature, (as in an ice calorimeter), is analogous to the interchangeability of weight and mass in a constant gravitational field.

A more positive indication that Carnot was introducing a new concept with his use of the word "calorique" is given in a footnote to his waterfall analogy:

> The matter here dealt with being entirely new, we are obliged to employ expressions NOT IN USE AS YET and which perhaps are less clear than is desirable. (Appendix—(g)).*

In view of this statement it appears manifestly unfair for the translators to identify Carnot's "calorique" with the conception implied by that word in the old caloric theory of heat.

In the statement quoted above, and in the waterfall analogy, this writer finds evidence for accepting "calorique" as entropy. This in turn permits the conservation of "calorique" without a violation of the First Law of Thermodynamics in a reversible cycle.

Brillouin[13] has observed that a code or cipher is always interposed between the thoughts of an author and his ability to convey them to another person through the medium of words. He implies that we should search for the spirit rather than the letter of Carnot.

Among other contributions, Carnot stated the conditions that would produce a perpetual motion machine of the second type. He used this principle to establish that his reversible cycle delivered maximum work between any two heat reservoirs.

Professor A. G. Christie[7] has pointed out many of the predictions in the memoir which have since become realities. Among these were the mercury vapor cycle and the gas turbine. Reference has already been made to the prediction of the triple-expansion steam engine.

The latter part of the memoir is devoted largely to discussions of the specific heats of gases. While this part of the work is most interesting, it has been omitted from this review as being of less immediate interest to engineers than the thermodynamic considerations of the cycle and the concept of entropy.

CONCLUSIONS

Writing in 1890, Thurston stated that:

> . . . Carnot was, perhaps, the greatest genius in the department of physical science at least, that this century has produced.
>
> Only now and then, in the centuries, does such a genius come into view.

In the sixty-eight years that have elapsed since, the stature of Carnot has, if anything, increased. At home and abroad he is recognized as one of the greatest scientists who ever lived.

Carnot's "Reflexions sur la Puissance Motrice du Feu" * presented some of the most profound truths ever uttered, and laid the foundations for the science of thermodynamics. Yet, as has already been pointed out, the fundamental ideas of the reversible cycle and the Second Law of Thermodynamics were fully revealed without recourse to any theory of heat.

The writer agrees with the Callendar-Brønsted-La Mer interpretation of "calorique" as entropy, which makes possible the fulfillment of the First Law of Thermodynamics within the framework of the memoir.

* * *

It is impossible to add to the stature of Carnot. One can only accord him humbler homage, a deeper appreciation.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. Theodor Gela and Dr. Robert H. Page, of the Stevens Institute of Technology, for reading the manuscript and for constructive suggestions. Source materials and other assistance was given me by Professor V. K. La Mer of Columbia University.

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* Italics by J.H.P.

* La Mer would render the original title as the "Motive Power" of "Fire" or "Flame," not "Heat" as has been done almost universally in the past. He points out that Ostwald translated "feu" as "feuer," i.e. as "fire."

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APPENDIX

(a) "La puissance motrice de la chaleur est indépendante des agens mis oeuvre pour la réaliser; sa quantité est fixée uniquement par les températures des corps entre lesquels se fait en dernier résultat le transport du calorique."

(b) "Partout où il existe une différence de température, partout où il peut y avoir rétablissement d'équilibre du calorique, il peut avoir aussi production de puissance motrice."

(c) "La production de la puissance motrice est donc due, dans les machines a vapeur, non a une consommation reele du calorique, MAIS A SON TRANSPORT D'UN CORPS CHAUD A UN CORPS FROID . . ."

(d) "La chute de calorique produit plus de puissance motrice dans les dégres inférieurs que dans les dégres supérieurs."

(e) "On peut donc poser en thèse générale que la puissance motrice est en quantité invariable dans la Nature; qu'elle n'est jamais, a proprement parler, ni produite, ni détruite. À la vérité, elle change de forme, c'est a dire qu'elle produit tantôt un genre de mouvement, tantôt un autre; mais elle n'est jamais anéantie."

(f) "Nous jugeons inutile d'expliquer ici ce que c'est que quantité de calorique ou quantité de chaleur (car nous employons indifféremment les deux expressions), in de décrire comment on mesure ces quantités par le calorimètre."

(g) "La matière ici traitée étant tout a fait nuovelle, nous sommes forcés d'employer des expressions encore inusitées qui n'ont peut-être pas toute la clarté, désirable."

Carrying out heat treating processes, such as annealing, tempering, or hardening, in a vacuum is a relatively new development in metallurgy. Experience by the Drever Company with various types of steels has indicated the advantages to be gained in certain applications by such processes. For example, the bright surfaces of stainless steel articles may be preserved during heat treating operations. In another case, the superior electrical properties of Armco iron are enhanced by the degassing of the metal which occurs when heated in a vacuum.

—from "Metal Progress," March 1958

RECENT DEVELOPMENTS IN BRITISH MAIN PROPULSION STEAM TURBINES

ACKNOWLEDGEMENT

This is an abstract, as published in the Annual Steam Number, 1957, of "The Marine Engineer and Naval Architect", of the first part of a paper read before The Institute of Marine Engineers on 8 October 1957. The authors were the late F. J. Cowlin and A. F. Veitch, of The English Electric Co., Ltd.

INTRODUCTION

During the wars in the Pacific where for tactical and strategic reasons it was necessary for British Naval craft to operate with comparable United States vessels, it became obvious that the steaming performance of the Royal Navy compared unfavorably with their American counterparts. This was accounted for partly by the lower steam conditions and partly by lack of development in aspects affecting turbine efficiency between the wars which had not kept pace with land steam practice. This state of affairs was caused no doubt by the shortage of financial backing for developing work generally in the marine industry.

Investigations were immediately instituted by the Royal Navy, and a Propulsion Committee, consisting of representatives of the warship building firms and the Department of the Engineer-in-Chief of the Fleet, was set up with suitable terms of reference. The several important differences in design and the basis of design between American and British ships quickly emerged.

As a result of its early deliberations, the Propulsion Committee decided to set up a number of special sub-committees, the one relevant to this paper being the Turbine Sub-Committee, the purpose of which was to co-ordinate marine and land turbine design techniques and make recommendations concerning future turbine designs for Naval purposes. The first meeting took place in London on the December 1, 1943, when representatives of the following organizations were present:—The Admiralty, John Brown & Co. (Clydebank), Ltd., The Parsons Marine Steam Turbine Co. Ltd., C. A. Parsons & Co., Ltd. and The English Electric Co., Ltd. Representatives of Metropolitan-Vickers Electrical Co., Ltd., and the British Thomson-Houston Co., Ltd., attended subsequent meetings.

The detailed work of this Committee resulted in the submission of five designs for turbines of 27,000 s.h.p. to meet an outline specification laid down by the Engineer-in-Chief's Department. These designs were openly tabled and adjudicated upon by the full Sub-Committee which unanimously decided that of the five designs the two submitted by the English Electric Co. best met the Admiralty requirements.

The first of these designs, referred to as S.T.N.1, was a two-cylinder reaction design preceded by a two-row Curtis wheel, based broadly on a design of which the U. S. Navy had supplied details. The second design, S.T.N.2, was of impulse construction making use of alloy steel rotors and originally referred to as a "limit" design, the total weight being some 30 per cent lower than that of any other design submitted.

The *Daring* class of destroyers was at this time (1944) under construction and the Admiralty decided to develop both S.T.N.1 and S.T.N.2 for installation in these ships after full shore tests had been carried out on prototype sets of machinery. In order to speed development, S.T.N.1 was entrusted jointly to Pametrada and C. A. Parsons & Co., Ltd., while the impulse design, S.T.N.2, was entrusted to the English Electric Co.

While the above developments were proceeding, a

third alternative design was introduced consisting of a British Thomson-Houston-designed H.P. cylinder and a Pametrada reaction L.P. cylinder. This was sponsored by John Brown and Co., eventually constructed by them and also shore tested at Pametrada following the tests on S.T.N.1. The three designs were referred to as:—

Daring I reaction design, first proposed by the English Electric Co. and developed by Pametrada and C. A. Parsons.

Daring II impulse reaction design H.P. cylinder by B.T.H., with L.P. cylinder as on *Daring I*.

Daring III advanced all-impulse type designed and developed by the English Electric Co.

The *Daring* Class twin-screw ships have main engines designed to meet the Admiralty requirements issued in 1944. Each set of turbines supplies 27,000 s.h.p. + 10 per cent overload with steam at 565 psia and 825°F. The steam pressure varies with the load, rising to 655 psia at 10 per cent power. The steam temperature remains constant. The vacuum at full power is 27.5 in. Hg. (Bar. 30.0 in.). An astern power of 9,000 s.h.p. is specified when supplied with steam at 515 psia, 825°F. The turbines were to be designed to attain a high efficiency at all powers with special emphasis on the range between 20 per cent and 40 per cent full power. During the life of the ship full power would not be required for more than 2,000 hours. The Admiralty stressed that interchangeability was particularly important, both for individual items and complete assemblies, irrespective of several manufacturers being involved.

"DARING III"

Preliminary investigations showed that the best turbine arrangement from the point of view of weight, space, and performance was a two-cylinder cross-compound arrangement with the power split more or less equally between cylinders at full load to ease the design of the double-reduction locked-train gear case. This arrangement, shown in Figure 1, was consequently adopted.

H.P. CYLINDER AND STEAM ADMISSION

In 1944 current practice in the Royal Navy was to install impulse-reaction H.P. turbines and all-reaction L.P. turbines, although some Brown-Curtis all-impulse turbines were still in service. This latter type was very much out of favor because of the serious troubles constantly arising from blade vibration, wheel flap and wheel loosening. It was felt, however, by the English Electric Company that for the requirements as stated above, an all-impulse design would prove advantageous, perhaps the major attraction being that the larger axial clearances permissible with impulse blading would considerably ease the problems of differential expansion between fixed and moving parts. In the case of the impulse H.P. cylinder, these clearances were at least five times greater than for the *Daring I* reaction turbine.

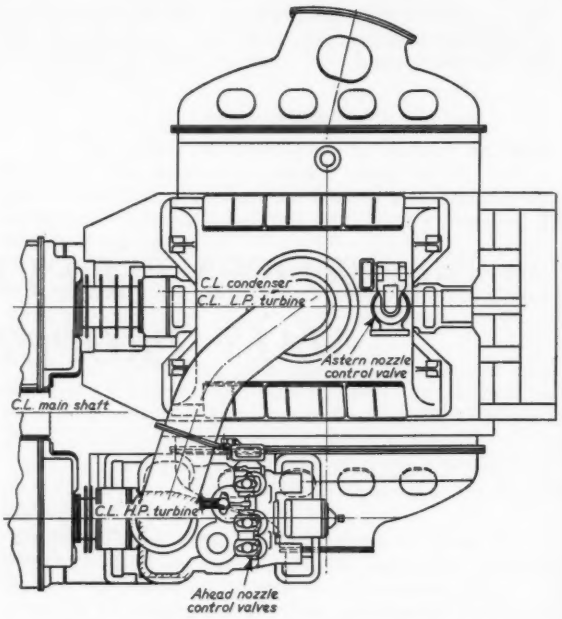


Figure 1—Turbine arrangement, *Daring III*

In addition, the rates of heating up and cooling down of a solid gashed type rotor approached much nearer that of the cylinder than did a drum type of rotor. This eased problems of differential expansion and eliminated wheel loosening. These points were of major importance in the case of naval machinery where speed of maneuvering and consequent rapid power change were essential. The wisdom of this decision was adequately proved during shore trials.

It was decided to use a steam chest cast integrally with the H.P. cylinder. This removed the complicated steam piping resulting from separate nozzle boxes and so improved habitability of the engine room. The valve gear fitted to all the turbines installed in the *Daring* Class was manufactured by J. Blakeborough and Sons, Ltd., to a design approved by the Admiralty. The individual valves were cam-operated when opening and spring-closing. The cams, of course, were designed by each turbine manufacturer to suit his own requirements.

In the interest of economy over the required power range, nozzle control valves were provided for loads of 20 per cent, 40 per cent and 60 per cent, each valve supplying steam to its individual group of nozzles. About 60 per cent power a bypass valve admitted steam to a belt situated between stages 3 and 4 in the H.P. turbine. All valves opened sequentially. The astern valve was mounted on the L.P. cylinder.

Two handwheels, one for ahead and the other for astern operation, were connected to the valve gear operating mechanism by means of bevel gears and shafting. No other control was required, thus operat-

ing duties were kept to a minimum and the correct number of nozzle groups for the power required always obtained.

L.P. CYLINDER

A double-flow L.P. cylinder, again incorporating a solid gashed type rotor, was decided upon, as this had numerous advantages over a single flow design when dealing with powers of the order required. Blade heights were halved, thus reducing very considerably the overall diameter. The shorter blades and smaller diameter rotor enabled the design to be based upon higher rotational speeds without any increase in stress levels; in addition, it permitted an astern Curtis wheel to be fitted at each end of the cylinder. This minimized rotor and casing distortion in comparison with single-flow construction and so favored rapid maneuvering.

MATERIALS

The abandonment of built-up rotors and the use instead of solid forged alloy steel rotors had permitted the employment of higher design stresses in the American designs. Although there was considerable controversy about the wisdom of using alloy steel for marine turbine rotors, the Admiralty, in collaboration with the forgemasters and the Turbine Sub-Committee, had put in hand an extensive program of trial forgings for sectioning and full analysis, as a result of which a 3 per cent chrome molybdenum steel was chosen for the rotors to an Admiralty specification now known as No. 3F.1.

Considerable difficulty was experienced by some steel makers in producing sound forgings in this material. But forging technique has now reached a level where this material is accepted as reliable by both land and marine turbine industries. It was only by the adoption of this material that the high rotational speeds of the *Daring* machinery were made possible.

BLADING

Chloride attack had been a frequent cause of trouble in naval turbines during the war; the Admiralty was concerned to fit blading resistant to this form of attack. Three choices of material presented themselves: Monel metal, Hecla A.T.V. steel, and stainless iron. Monel metal was avoided due to its high specific weight, adding appreciably to the blade and wheel stresses. Stainless iron, of course, was little more resistant to chloride attack than mild steel and necessitated particular attention to feed water purity if it were to be used in marine turbines, both in ordinary operation and under action conditions, especially if damage occurs to the machinery. A.T.V. steel was eventually chosen for *Daring III* with the exception of the last two L.P. rows of blading, whch were made of a special manganese-nickel steel and chromium plated in line with the maker's established land practice.

All the fixed blading took the form of nozzles, and here, with the exception of the last two stages, a built-up construction was employed consisting of A.T.V. steel nozzle segments fixed to mild steel centers. The last two L.P. diaphragms were made of cast steel with A.T.V. steel nozzle division plates cast in. Shock conditions due to underwater explosion precluded the use of cast iron on Naval vessels

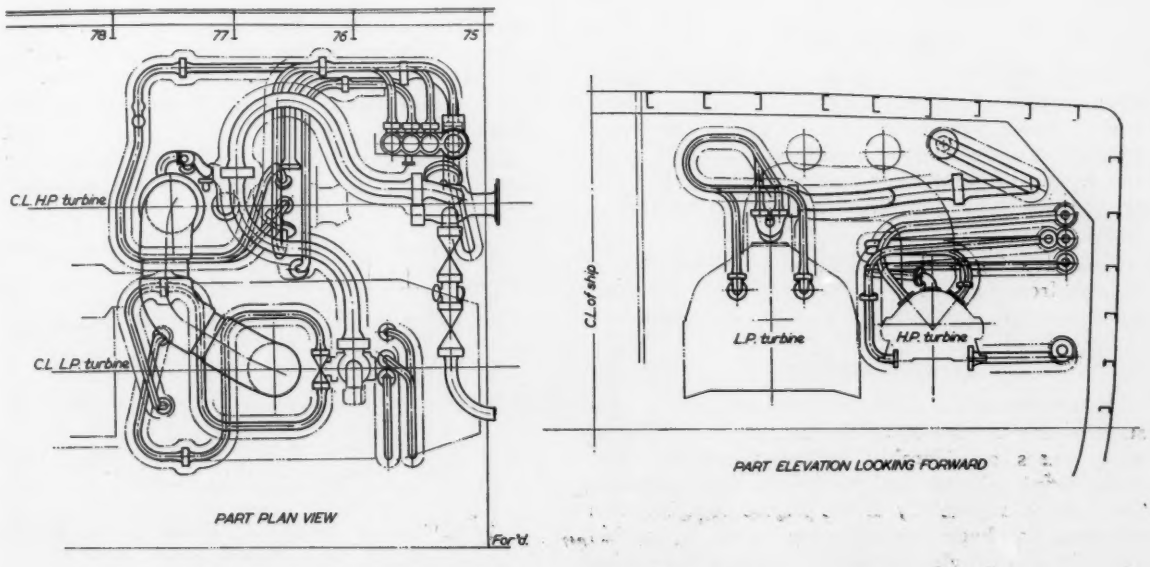


Figure 2—Steam chest and piping, *Daring I*

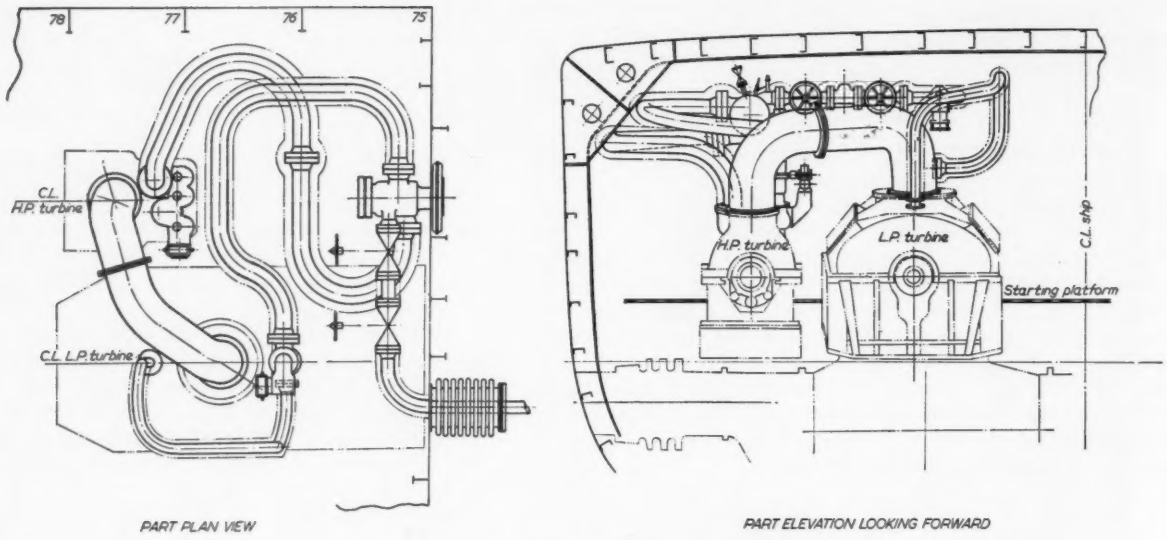


Figure 3—Steam chest and piping, *Daring III*

and restricted the materials for casings, pedestals, etc., to cast steel or fabricated mild steel.

TABLE 1

	Daring III	Daring II	Daring I
2 H.P. turbines, including valves, pipes, etc., tons	21.2	45.3	38.0
2 L.P. turbines, including valves, pipes, etc., tons	37.8	44.1	44.1
Total	59.0	89.4	82.1
H.P. rotor bearing centers	4 ft. 9¼ in.	5 ft. 10¼ in.	6 ft. 7⅜ in.
L.P. rotor bearing centers	7 ft. 10 in.	8 ft. 6⅝ in.	8 ft. 6⅝ in.

WEIGHT AND SPACE

Due to the increasing demand on modern Naval ships for more and more space for armament and other fighting equipment there is greater need for lighter and more compact machinery. Reduced space and weight of machinery means that the ship can carry more fuel, and thus improve its radius of action.

The advantages of the integral steam chest can be seen from Figures 2 and 3, while Table 1 throws additional light on the topic of weight and space.

INTERCHANGEABILITY

Interchangeability could only be achieved by the suitable tolerancing of all dimensions, involving in many cases considerably tighter tolerances than those previously worked to for marine purposes. That interchangeability to the degree required was achieved has been proved many times. A notable example was provided when a complete H.P. rotor made by one manufacturer was fitted in a finished casing made by another, no hand fitting or adjustment being required.

SHORE TRIALS

Figure 4 shows the steam consumption rate including gear losses for *Daring III* turbines over the power range based on the shore trial results. There was but little difference between the specific steam consumptions for *Daring I, II* and *III* as no design proved superior to any other over the whole power range. It can be seen how closely the specified requirements have been achieved, the curve being practically flat from 20 per cent to 100 per cent power, the lowest point being at about 40 per cent power. All three designs of machinery proved satisfactory in their ability to maneuver, particularly so for the all-impulse design H.P. cylinder of *Daring II* and *III*.

Resulting from the full-scale shore trials, it was found that all three designs could be improved in

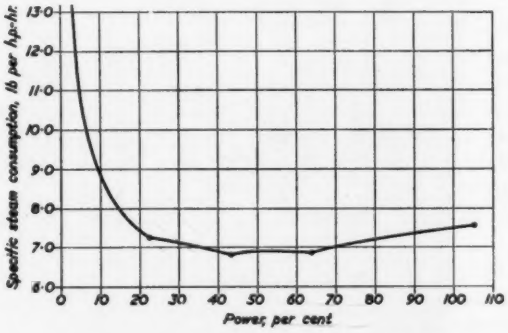


Figure 4—Consumption rate, *Daring III*

one way or another, as was to be expected when testing machinery of such an advanced character for the first time. In nearly all cases the modifications were of a comparatively minor nature. In the case of *Daring III* vibration trouble was revealed upon opening up the L.P. cylinder after the trials. This concerned the lacing wires and blading in the later ahead stages and was overcome by providing a more efficient type of steam deflector between the ahead and astern blading. The modification consisted in substituting a deflector bolted to the casing in place of the one designed integral with the rotor.

Examination of the blading in the H.P. cylinder revealed failures in one or two segments of the Hecla A.T.V. lacing wires where brazed to the blade. Resulting investigations revealed that Hecla A.T.V. steel was subject to intergranular penetration by copper during brazing operations, but was otherwise quite suitable if brazing was avoided. This difficulty was overcome by replacing all laced rows of blading and substituting high tensile stainless iron for both blades and lacing wires.

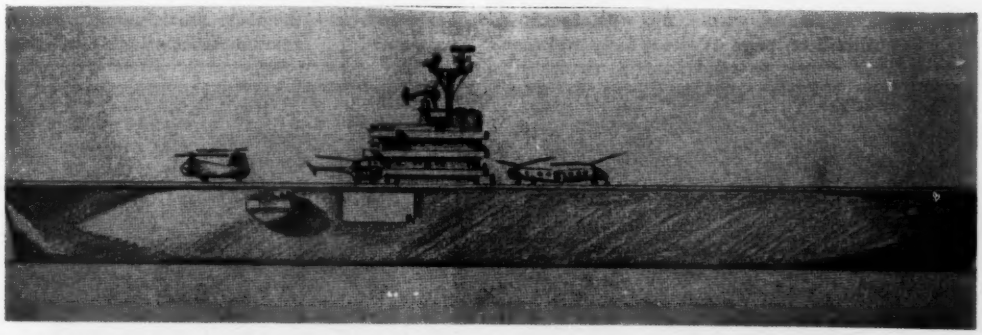
It was also established during the trials that the measured steam flow was greater than the first-stage nozzle area would theoretically permit; steam tests carried out at Rugby Works revealed that there was steam leakage between the built-up nozzle segments. This permitted steam to enter the casing *via* the horizontal joint of the nozzle plate. This trouble has been overcome by substituting a solid type of nozzle plate in which the segments are integral with the center and machined from the solid. (This is the type of trouble which could not be detected without the full scale test facilities of Pametrada.)

CONCLUSIONS

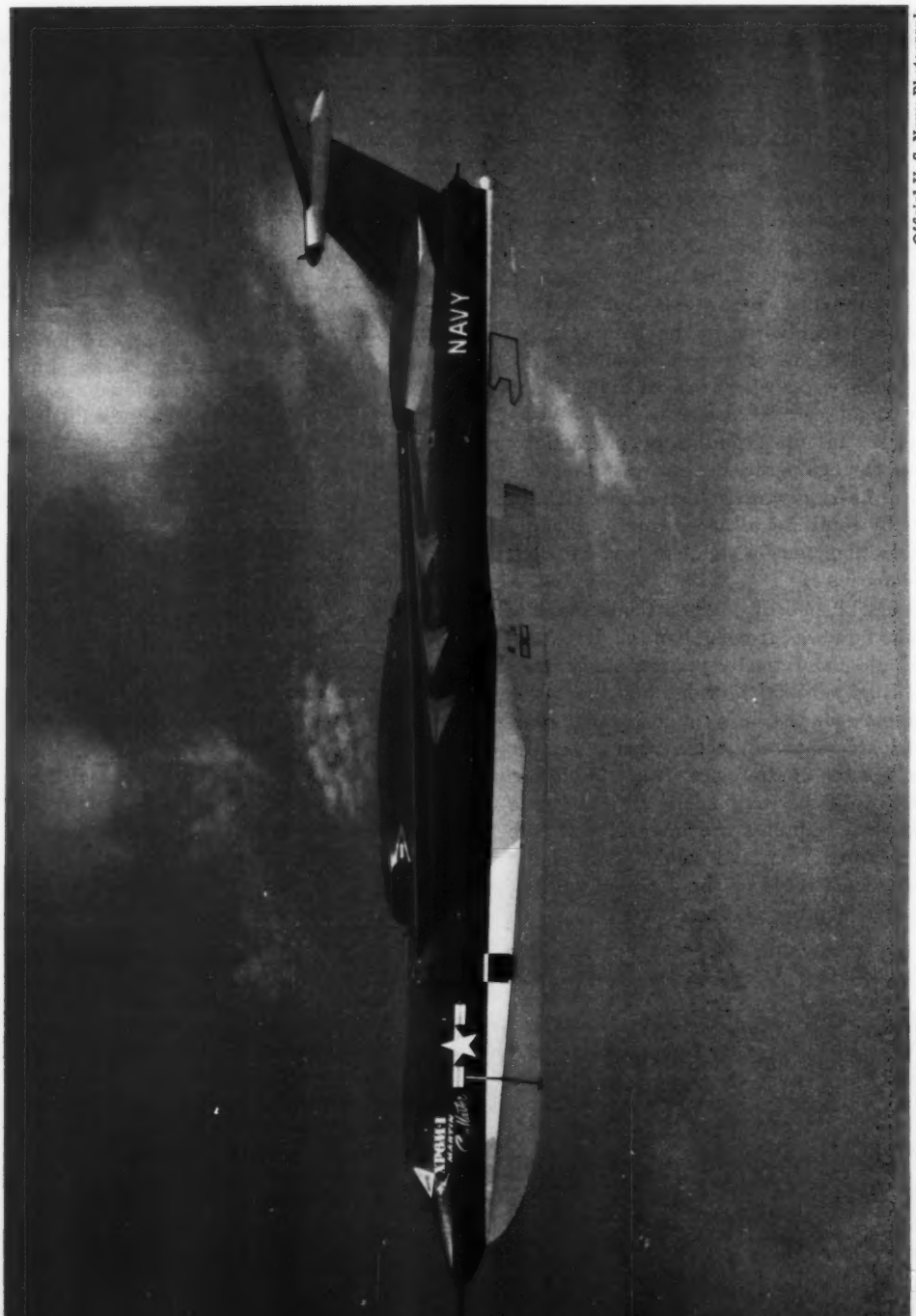
The *Daring III* turbines produced an economy combined with weight and space figures superior to any other main propulsion unit for Naval purposes previously built in this country. H.M.S. *Decoy* and *Diana*, fitted with this design, have both been in service for some three or four years and have given every satisfaction to date. H.M.S. *Decoy* is installed with the prototype port set of turbines built by the English Electric Co.; the starboard set and both sets in H.M.S. *Diana* were built by Yarrow and Co., Ltd., under licence from the English Electric Co. Turbines of the *Daring III* design are also being manufactured in Australia at Cockatoo Dockyard for installation in the Australian-built *Daring* Class ships, the first of which successfully completed sea trials last summer. Table 2 summarizes the salient features of the *Battle* Class, *Weapon* Class and the *Daring III* propulsion machinery for purposes of comparison.

TABLE 2.

	Daring III	*Weapon* Class	*Battle* Class
Full power s.h.p. per set	27,000	20,000	25,000
Steam conditions at full power, lb. per sq. in.	550	350	350
deg. F.	825	750	650
Steam consumption at 20 per cent power, lb. per s.h.p. hr.	7.25	8.8	9.8
Steam consumption at 100 per cent power, lb. per s.h.p. hr.	7.52	7.7	8.4
Specific weight of turbine, lb. per s.h.p.	2.45	4.74	4.83
H.P. rotor, bearing centers	4 ft. 9¼ in.	9 ft. 11 in.	9 ft. 4¼ in.
L.P. rotor, bearing centers	7 ft. 10 in.	11 ft. 8⅞ in.	12 ft. 6¼ in.



TO BUILD IN '59—Artist's conception of the LPH-2 (Amphibious Assault Ship) construction of which is slated to begin at Puget Sound Naval Shipyard on July 1, 1959. It is the first of its type to be built from the keel up for helicopter carrier use. Puget Sound Naval Shipyard is the lead planning yard for design and construction.



Official U. S. Navy Photograph

Martin P6M *Seamaster* in flight

D. A. CARRISON & C. O. SMITH

WHAT IS A NUCLEAR REACTOR?

THE AUTHORS

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NUCLEAR REACTOR technology is about fifteen years old but in spite of the vast effort expended in this field it is still an immature technology. Despite many references to nuclear reactors in public print, the basic question, "What is a nuclear reactor?" is still unanswered for many people. If we consult a dictionary, it is quite likely we will not find a definition, or if we find one it probably is not very satisfactory.

If we continue our search for an answer by asking someone who is connected with the nuclear energy business, it is probable that the answer will depend to a great degree on the individual. For instance, the experimental physicist sees a nuclear reactor as a source of neutrons and gamma rays which he needs for his experiments. The theoretical physicist sees a reactor as the place where all the phenomena of the nuclear chain reaction take place. The utilities man sees a reactor as simply another heat source which can be coupled with more-or-less conventional steam plants to produce heat or electricity. The materials engineer thinks of a reactor as one big headache since he is given the task of finding at least one material that is inexpensive, easy to fabricate, impervious to radiation effects, strong and stable at elevated temperatures (the higher the better), highly corrosion resistant, readily dissolved for chemical reprocessing, not subject to induced radioactivity, and provides excellent shielding. The military man sees a reactor as a wonderful source of power requiring a minimum of logistic support to keep it operating. Depending on the color uniform he wears, he wants to put a reactor in a ship, aircraft, tank, or just on the ground. We get still different answers as we ask other specialists.

At this point, the bewildered individual is tempted to throw up his hands and admit that he is more thoroughly confused than before. But he need not despair since it is possible to find a reasonably inclusive definition such as; *"A nuclear reactor is a device designed to produce and sustain a controlled fission chain reaction."* The words *sustain* and *controlled* should be noted with some emphasis since they indicate the fundamental difference between a nuclear reactor and an "atomic" bomb.

THE FISSION PROCESS

In essence, the basic purpose of a nuclear reactor is to achieve the release of fission energy in a controlled and usable manner. Fission is the name given to the reaction in which a free neutron (the uncharged constitutent of the nucleus of the atom) is absorbed by the nucleus of a fissile atom (one capable of fissioning) and causes it to split into two smaller atoms (or fission fragments) as indicated in Figure 1. This splitting of the nucleus is accompanied by the release of some neutrons and about 200 Mev (million electron volts) of energy per fission, this energy being principally in the form of kinetic energy of the fission fragments and neutrons. The energy appears in the form of heat from the slowing down of these pieces as they collide with other atoms in the material. Since one Mev=1.6 x 10^{-13} watt-sec, the fission of one U^{235} nucleus releases about 3.2×10^{-11} watt-sec of energy. Thus about 3.1×10^{10} fissions per second are required to produce one watt of power. In somewhat different terms, energy release at the rate of one megawatt (10^6 watts) will provide enough boiling water for about 10 to 15 cups of coffee per second, depending on the efficiency and operation of the boiler and will require fission of about 3.1×10^{16} atoms per second.

We know that there are about 2.5×10^{21} atoms per gram of uranium so that the complete fission of one gram of uranium would release 8.2×10^{10} watt-sec of energy, or 2.3×10^4 kilowatt hours, i.e., nearly 1 megawatt day. If one kilgram of U^{235} (2.2 lbs) were to undergo complete fission over the period of one day, this would be approximately 1000 megawatts of heat. If this were converted to electricity with a conversion efficiency of 30 per cent, this is equivalent to the electricity produced from a large "conventional" power plant which consumes about 2500 tons of coal per day. In other words, fissioning of a gram of uranium yields approximately one million times as much energy as is released by the same quantity of uranium undergoing a chemical reaction such as oxidation. This comparison between nuclear energy and chemical energy is one of the major unique features of nuclear reactors.

We might note that there is only one naturally occurring isotope which fissions readily. This is the isotope of uranium having an atomic weight of 235 (U^{235}). This isotope constitutes about 0.7% of natural uranium with the balance U^{238}. There are two other fissionable isotopes of practical interest, Pu^{239} and U^{233}, which can be produced as a result of neutron reactions with U^{238} and Th^{232}, respectively, as we shall see later.

The Chain Reaction

A uranium atom upon fissioning produces or releases 2.5 neutrons on the average. The achievement of a chain reaction, which is required in a nuclear reactor, depends on the result of competition for these neturons among four processes:

1. Fission of uranium nuclei, with emission of additional neutrons.
2. Non-fission capture of neutrons by uranium.
3. Non-fission capture of neutrons by other materials.
4. Leakage, i.e., escape of neutrons without being captured.

If the loss of neutrons by the last three processes is less than or equal to the surplus produced by the first, the chain reaction occurs; otherwise it does not. In other words, a chain reaction, or continuous fission, is possible only if at least one neutron released by fission successfully causes fission in another fissile nucleus. Obviously, the ultimate use of the neutrons, i.e., the neutron economy, is of prime importance in reactor design.

Critical Size

The necessity for a favorable neutron balance establishes certain conditions on a system in which a chain reaction is desired. One of these conditions is size. If uranium is distributed in some regular fashion in an assembly, the production of neutrons depends on the volume while the probability of escape depends on the surface area. In a very small system the surface-to-volume ratio is large and too many of the neutrons escape to achieve a chain reaction. The loss of neutrons by nonfission capture depends

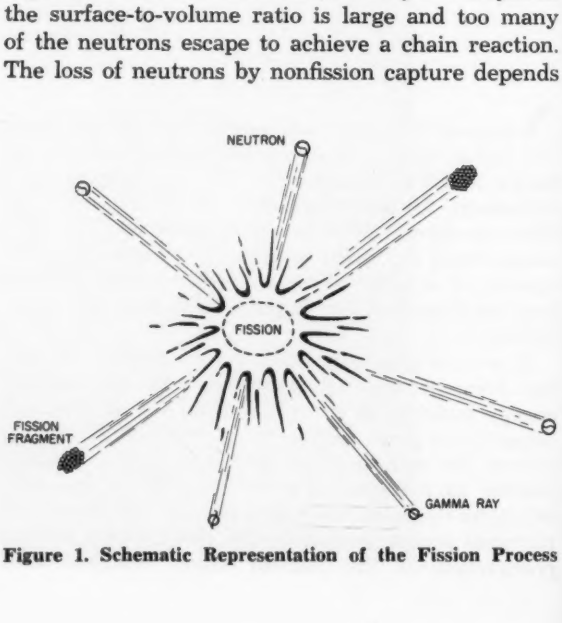

Figure 1. Schematic Representation of the Fission Process

on the volume but its relative importance does not change with the size of the system. Thus the greater the size of the system, the less are the escape of neutrons and their nonfission absorption likely to outweigh their production. For any given geometry there is a certain size, called the *critical size*, for which the production of neutrons by fission just balances their loss by nonfission capture and escape and a chain reaction is possible. The requirement of a critical size for a fission chain reaction to "go" provides a sharp contrast with chemical reactions which may proceed regardless of the size of the system.

The Neutron Cycle in a Thermal Reactor

The neutrons released at fission are very energetic with kinetic energies of up to several Mev although the average is about two Mev. These neutrons are known as "fast" neutrons with kinetic energies corresponding to velocities in the order of 40 million miles per hour. If these fast neutrons collide with uranium atoms there is an excellent chance of losing some of their energy without either being absorbed or producing fission. These slower neutrons are unable to produce fission in U^{238} but can do so in U^{235}. These slower neutrons may also continue to slow down, be captured or absorbed by the various materials present, or leak (escape) from the system. When the neutron energy has been decreased to about 10 ev, a "resonance" region is encountered in uranium. This essentially means that U^{238} has an extra large "appetite" for neutrons whose energies are in the vicinity of 10 ev. Neutron absorption by U^{238} occurs so readily at these energies that too few neutrons are left to sustain a chain reaction in pure natural uranium regardless of the size of the system. The neutrons which get below the resonance region will be in the same manner as above, i.e., fission U^{235}, be captured, continue to slow down, or leak from the system. Neutrons of any energy can cause fission in U^{235}, however, and a chain reaction can be achieved with a relatively small mass of this isotope. "Atomic bombs" of U^{235} have been used and a nuclear reactor has been designed, built, and operated using U^{235} as a fuel in which fissions are induced by fast neutrons.

A chain reaction can be achieved in natural uranium, however, if the uranium is arranged in a regular pattern of small lumps so that many of the fast neutrons diffuse out of the uranium into the surrounding material where most of them are slowed down below resonance absorption, before diffusing back into the uranium. Thus a higher proportion of neutrons is preserved for the fission of U^{235} by making them less likely to be caught by U^{238}. This material which helps the neutrons lose energy and keeps them in "custody" until they are relatively safe from capture by U^{238} is known as a moderator. It is obvious that the moderator must not absorb too many neutrons or the reaction will be stopped. In effect, the fast neutrons released by fission are not as easy to "catch" as are slower neutrons so we allow them to wander around in the moderator and reduce their energy (and corresponding speed) to that corresponding to the ambient temperature. In other words, they are then in thermal equilibrium with the atoms or molecules of the moderator. Such neutrons are called *"thermal"* and have kinetic energies in the order of 0.025 ev implying a speed of about 5000 mph. The probability of a U^{235} nucleus fissioning is about 300 times as great with a slow (thermal) neutron as with a fast neutron. Suitable moderators are light and heavy water, graphite, beryllium and beryllium compounds.

The neutron balance in a thermal reactor can best be described in terms of a cycle that shows what happens to the neutrons. Let us consider a cycle, Figure 2, which starts with the fission of a U^{235} nucleus by a thermal neutron. Due to fission, ν fast neutrons are emitted. Some of these may cause fission of U^{238} nuclei. For this to occur, the fast neutrons must collide with U^{238} nuclei before colliding with moderator nuclei. The small fraction of neutrons causing fission in U^{238} produces additional fast neutrons. Thus the total number of fast neutrons is increased from ν to $\nu\varepsilon$, where ε, the fast fission factor, is equal to or greater than unity.

The $\nu\varepsilon$ neutrons move randomly through the uranium-moderator system. Many of them are slowed down but a fraction l_f (fast leakage) escapes before reaching thermal energies so that $\nu\varepsilon\, l_f$ neutrons are lost to the chain reaction. The remaining $\nu\varepsilon\,(1-l_f)$ neutrons are slowed to thermal energies by the moderator atoms. During this process, however, $\nu\varepsilon\,(1-l_f)\,(1-p)$ neutrons are captured by U^{238} to form U^{239} which decays to Np^{239} and then to Pu^{239}. The remaining $\nu\varepsilon\,(1-l_f)\,p$ neutrons escape capture. The quantity p is called the resonance escape probability. Although the neutrons captured by U^{238} are lost in the sense of causing further fission of U^{235}, they contribute to the production of Pu^{239} which is fissionable.

The $\nu\varepsilon\,(1-l_f)\,p$ neutrons are slowed to thermal energies. Some of these neutrons move around the system and escape. If the fraction escaping is l_t (thermal leakage), there are $\nu\varepsilon\ (1-l_f)\ p\ (1-l_t)$ neutrons left. Of these, a fraction f (known as the thermal utilization factor) will be absorbed in the uranium and the remaining fraction (1−f) will be absorbed in other materials such as the moderator, structural materials, and coolant. Of the $\nu\varepsilon\,(1-l_f)\,p\,(1-l_t)\,f$ neutrons absorbed by uranium, a fraction g will cause fission and the remaining fraction (1−g) will be absorbed to form U^{239} where g is

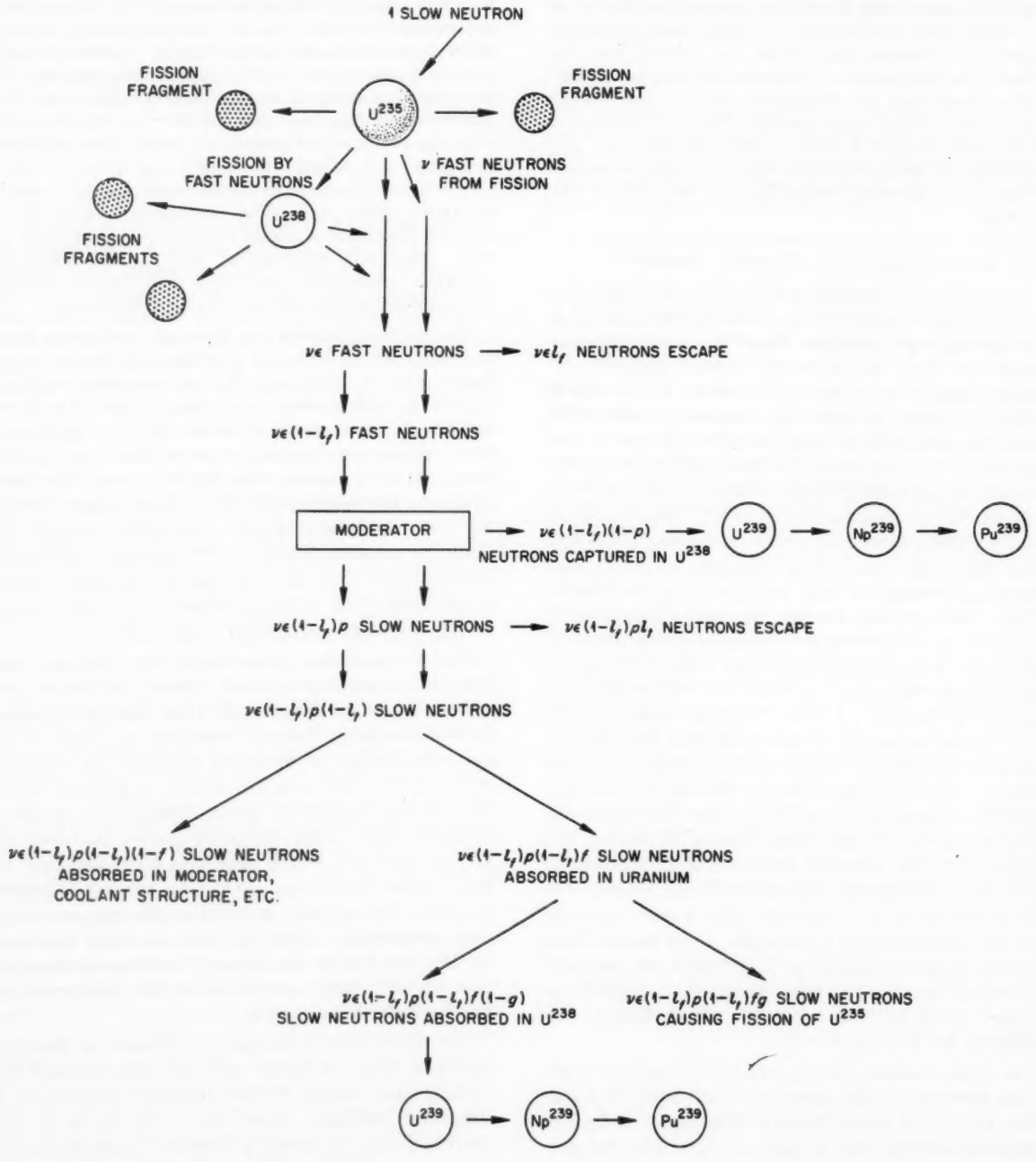

Figure 2. Schematic Representation of the Neutron Cycle in the Chain Reaction of Uranium Fission by Thermal (Slow) Neutrons.

the ratio of the fission cross section* to the absorption cross section. The number of neutrons which cause fission and thereby start a second cycle is $\nu\varepsilon(1-l_f)p(1-l_t)fg$.

This number of second generation fissions in U^{235} per fission of U^{235} by a first generation neutron is called the *reproduction factor* or *multiplication factor* and is denoted by k. It follows that

$$k = \nu\varepsilon(1-l_f)p(1-l_t)fg$$

The product νg is the number of (fast) fission neutrons produced for each thermal neutron absorbed in uranium and is called η. We rewrite the equation as

$$k = \eta\varepsilon pf(1-l_f)(1-l_t)$$

This quantity k is usually known as the *effective* multiplication factor and applies to a system of finite size. To have a chain reacting system in a steady state k must be unity, i.e., the system is just "critical." If k is less than unity, no chain reaction is possible and the system is "subcritical"; if k is greater than unity the numbers of neutrons and fissions increase from cycle to cycle and the chain reaction is said to be divergent or the system is "supercritical."

The value of k for an infinitely large system is especially useful in the theory and preliminary design of nuclear reactors. Since there can be no leakage from an infinite system, l_f and l_t are both zero and the multiplication factor becomes

$$k_\infty = \eta\varepsilon pf$$

which is known as the *four factor formula*. Of these four factors, η depends only on the nuclear properties of the fuel while ε depends on the size and shape of the fuel as well as its nuclear properties. The other two quantities, p and f, depend on the nuclear properties of the fuel, moderator and all other materials present, and on the manner in which these materials are arranged. In reactor design, we desire to maximize the product pf.

CONTROL OF A REACTOR

If a reactor were built exactly critical size, then after a "few" fissions we might expect it to become subcritical since we are removing U^{235} atoms from the system. In addition, we would have no neutrons available to conduct experiments. Consequently, a reactor is constructed with a certain amount of excess fissionable material. Thus k is greater than unity and the number of neutrons present increases by the compound-interest law. If k is very large so that a great multiplication takes place in a fraction of a second, there is an explosion, i.e., a sort of "atomic bomb." Even if this reaction occurred slowly, the reactor would be destroyed by melting if the multiplication were to continue indefinitely.

One way in which control can be exercised is to provide channels through which rods made of materials that strongly absorb neutrons (e.g., cadmium, boron steel, certain rare earth elements) can be passed. If the rods are fully inserted into the fissioning system, they absorb so many neutrons that the chain reaction stops. If they are slowly withdrawn, a point is reached at which the chain reaction just maintains itself. If they are withdrawn further, the neutrons multiply and the reactor operates at an increasing power level. To reduce the multiplication rate, the rods are pushed in again. Thus to raise the power output, the rods are withdrawn until the desired level is reached and then *returned* to the operating point while the reactor continues operating at the increased level. This is in contrast with conventional power plant controls, e.g., to increase the firing rate of an oil-fired boiler, the fuel valve is opened wider and the air flow increased.

The preceding discussion implies that the time factor is slow enough for an operator to maintain control by manual operation or other similar relatively slow acting mechanism. This can be done, but only because of the phenomenon of *delayed* neutrons. For U^{235}, about 99.25% of the neutrons are released by the nucleus practically instantaneously (in about 10^{-14} second) after fission occurs. These are known as *prompt* neutrons. The fission fragments are in a highly unstable condition and some of them release additional neutrons (the other 0.75%) over a period averaging about 20 seconds. Reactor control systems are designed on the basis of handling the delayed neutrons.

SIMPLE CONCEPT OF A REACTOR

The discussion relative to the neutron cycle was in terms of a thermal reactor, i.e., one in which most of the fissions are caused by thermal neutrons. The basic concept of a simple thermal reactor is shown in Figure 3. In this reactor, the fuel is physically located in fuel elements which have the uranium in the form of "pure" metal, a metallic alloy, or a ceramic, encased in another metal or alloy which serves as (1) a mechanical support, (2) a container to keep the fission products inside the element, and (3) a protection of the fuel against corrosion by the coolant. The fuel elements are arranged in a regular pattern with the moderator. This arrangement of fuel and moderator in a regular pattern so that a non-homogeneous medium is presented to the neutrons classifies the reactor as heterogeneous.

* As a neutron passes through an assemblage of atoms, the probability of its colliding and reacting in a particular fashion with a particular atom depends upon the effective size or "cross section" of the nucleus of the atom. This effective size is usually expressed in units of 10^{-24} cm^2 called barns. This effective size bears no direct relationship to atomic sizes as normally determined and varies greatly from one isotope to another and to some extent with the energy or velocity of the neutron. Fission cross section is a measure of the probability of collision followed by fission of the nucleus of the atom in question. Likewise, absorption cross section is a measure of the probability of collision followed by absorption of the neutron by the nucleus.

The fuel-moderator "core" is surrounded by a reflector, a material which can also serve as a moderator. The purpose of the reflector is to act as a "mirror" and "reflect" neutrons back into the core so that the leakage or escape of neutrons will be minimized and thereby improve the neutron economy. On the exterior, completely enclosing the entire reactor, is shielding. Shielding absorbs the leakage neutrons and gamma rays and reduces their intensity to a level which can be tolerated by human beings. A control rod (usually several rods) serves to exercise control and maintain a steady state of operation.

There is one important item missing from Figure 3, namely the coolant. We recall that each fission is accompanied by the release of about 200 Mev of energy. Approximately 170 Mev of this energy is in the form of kinetic energy of the fission fragments, and the other 30 Mev is associated with the neutrons, beta rays, gamma rays, and neutrinos. Since the fission fragments rarely travel further than about 0.0005 inch from the point of fission, most of the fission energy is transformed into heat close to the point of fission. In order to operate in a steady state condition, this heat must be removed. This is normally done by circulating a coolant through the reactor. The coolant can be a gas (e.g., helium, air, carbon dioxide) or a liquid (e.g., light or heavy water, organic liquids, liquid metals, molten salts). The choice of coolant depends on the purpose of the reactor and is limited by nuclear and engineering considerations. The coolant almost always adds to the nonfission capture of neutrons and the loss in neutron economy must be balanced against the efficiency of heat removal.

Classification of Reactors

So far our discussion has been mainly in terms of a thermal, heterogeneous reactor, primarily since this is the type which was first operated and which is most numerous. We should not be misled, however, into thinking that this is the only possible reactor type since there are a large number of reactors which differ in purpose, power level, type of fuel, fuel arrangement, and so on. Nuclear reactors can be classified according to the characteristics of the individual chain reacting system and other features as indicated in Table 1. Any given reactor can be described in terms of the factors, e.g., the first permanent reactor, the X-10 at Oak Ridge National Laboratory, can be described as a thermal, natural uranium, heterogeneous, solid fuel, graphite moderated, air cooled, burner, research reactor. All nuclear reactors, however, regardless of description, require a sustained fission chain reaction for continued operation.

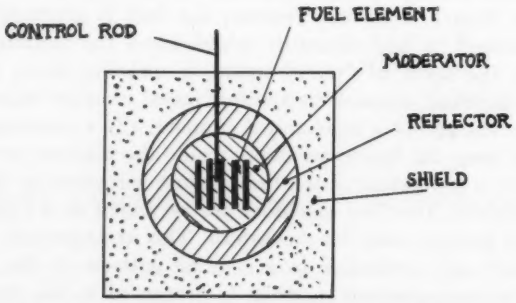

Figure 3. Schematic Heterogeneous Thermal Reactor.

TABLE 1—*Classification of Nuclear Reactors*

A. Neutron Energy at Which Most of the Fissions Occur
   1. Fast (greater than about 100,000 ev)
   2. Intermediate
   3. Thermal (less than 0.1 ev)

B. Purpose
   1. Research and Development
   2. Production (of fissile material)
   3. Power

C. Fuel
   1. Natural uranium, 0.7% U^{235}, balance U^{238}
   2. Enriched uranium, more than 0.7% U^{235}, Balance U^{238}
   3. Plutonium-239
   4. Uranium-233

D. Fuel—Moderator Geometry
   1. Heterogeneous
   2. Homogeneous

E. Fuel Matrix
   1. Solid
   2. Liquid

F. Fuel Consumption
   1. Burner
   2. Converter
   3. Breeder

G. Other
   1. Moderator
   2. Coolant

Neutron Energy for Fission

Nearly all of the nuclear reactors which have been built or proposed are thermal, i.e., the neutrons causing fission are in thermal equilibrium with the atoms or molecules of the moderator. The *Seawolf*, SSN-575, has an intermediate reactor and there are a few fast reactors (e.g., Los Alamos Fast Plutonium Reactor ("Clementine"), Experimental Breeder Reactor-1, Dounreay Fast Power Breeder, etc.) which have the majority of their fissions caused by fast, i.e., highly energetic, neutrons. Thermal reactors always have moderating material, fast reactors have none, and intermediate reactors may have some.

Heterogeneous vs. Homogeneous

The distinction between heterogeneous and homogeneous reactors is based on the medium presented to the neutrons. If the fissionable and

moderating materials are arranged as discrete bodies (usually in some regular pattern) or such dimensions that the neutrons see a non-homogeneous medium, this is a heterogeneous reactor. If, however, the fissionable and moderating materials are combined in a mixture so that an effectively homogeneous medium is seen by the neutrons, this is a homogeneous reactor. The mixture may be a true solution or it may be a suspension of discrete particles having dimensions which are small in comparison with the mean free path of the neutrons.

Solid Fuel vs. Liquid Fuel

The distinction between heterogeneous and homogeneous might seem to imply that an additional distinction between solid and liquid fuel is redundant. It is true that heterogeneous reactors are usually solid fueled and homogeneous reactors are liquid fueled, but it is possible to have a heterogeneous reactor with liquid fuel. An example of this is the Liquid Metal Fuel Reactor which has been designed by Brookhaven National Laboratory and is being built by Babcock and Wilcox. Solid fuels may be in the form of "pure" metallic fuel, alloys containing fuel, or a ceramic. Liquid fuels may be in the form of an aqueous or organic solution, liquid metal, molten salt, or a slurry, i.e., a suspension of small solid particles in a liquid medium. It is conceivable that fuels might be gaseous, but this possibility has been given rather limited consideration.

Fuel Consumption

Many of the reactors which have been built are considered to be "burners," i.e., the fissionable isotope (usually U^{235}) is consumed by the fission process in much the same manner as fossil fuel is used up by combination with oxygen in some kind of a furnace. We recall that U^{235} is only about 0.7% of natural uranium and we also know that workable deposits of uranium ore appear to be limited. This would appear to greatly limit the future of nuclear energy if it were not for the fact that it is possible to transmute certain isotopes into fissionable isotopes.

In our discussion of the neutron cycle in a thermal reactor, we indicated that some of the neutrons are captured by U^{238}. This forms a new isotope, U^{239}, which is radioactive and decays with a half life (half life is time required for one-half of any quantity to decay) of 23 minutes to Np^{239} by emission of a beta particle, i.e., an electron. This in turn decays with a half life of 2.3 days to Pu^{239} by emission of a beta ray. Pu^{239} has a half life of about 24,300 years. It is possible to produce U^{233} from Th^{232} by a similar reaction. Both Pu^{239} and U^{233} are "synthetic" or "artificial" isotopes in the sense that they are not found in nature in other than trace quantities. Both are fissionable and can either be removed from the reactor and used as fuel in other reactors or be "burned" in place to augment the lifetime of the reactor.

We recall the fission of a U^{235} atom emits 2.5 neutrons on the average. One is required to sustain the chain reaction leaving 1.5 neutrons to generate new materials and take care of losses due to capture and leakage. If a reactor produces as much fuel as it consumes, one neutron must be used to generate the new fuel, leaving only 0.5 neutron for leakage and nonfission capture. Thus a reactor which generates new fuel places a great premium on neutron economy. This can be done by careful design to minimize leakage, by choice of materials with low absorption cross section, and by using fast reactors.

A *converter* is a reactor that converts fertile atoms into fissionable atoms by neutron capture as described above. There are two different meanings of converter and breeder: (1) A *converter* is a reactor that uses one kind of fuel and produces another (e.g., consumes U^{235} and produces Pu^{239} from U^{238} as in the Hanford production reactors) while a *breeder* produces the same kind of fuel (e.g., consumes Pu^{239} and produces more Pu^{239} from U^{238}). (2) A *breeder* is a *converter* that produces more fissionable atoms than it consumes. The physics of the process of fuel generation is essentially the same in either case. The second of these meanings is more general and is the sense used in the following discussion.

PURPOSES OF REACTORS

Reactors are classified by purpose as research, production, or power although these classes are not mutually exclusive since a given reactor may be designed for a combination of uses. At present, the largest group of reactors are considered as research and development reactors. These are reactors which may be primarily for releasing neutrons for various physical experiments, for educational and training purposes, or for evaluating (on a pilot plant or prototype scale) a design which is being developed for possible power production. Production reactors are used to produce fissionable material from fetrile material, e.g., the conversion of U^{238} to Pu^{239}. The reactors at Hanford, Washington, and at Savannah River, South Carolina, are examples of production reactors. Power reactors are those which are built and operated for the purpose of producing heat and/or electrical energy. There are very few reactors which strictly qualify in this category at the present time due to the stage of development of the technology. The Experimental Boiling Water Reactor at Argonne National Laboratory and the Army Package Reactor at Fort Belvoir, however, can be considered power reactors. Both are much smaller than the reactors which are expected to be eventually used in central power stations or even the Calder Hall reactors.

GRAPHITE MODERATED REACTORS

From the historical viewpoint, the first reactor was the one built under the stands of the University of Chicago stadium (CP-1) which went critical on December 2, 1942. While this was not much of a reactor in comparison with some now building or proposed, it was highly significant in that it demonstrated that nuclear reactors could be built and made to operate. This graphite moderated reactor went critical on 296 Kg of U^{235} in the form of natural uranium metal, UO_2 and U_3O_8. This "pile" was shut down in February of 1943, dismantled, rebuilt at Argonne National Laboratory, and operated as CP-2 from March, 1943 to March, 1954. The reactor was dismantled in 1955-56.

The first permanent reactor was the X-10 located at Oak Ridge National Laboratory. This reactor was built as a prototype for the production reactors at Hanford, but is now used as a neutron source for research purposes and isotope production. The X-10 is a graphite moderated, air-cooled, natural uranium fuel, thermal reactor with the general arrangement shown in Figure 4. The X-10 and Hanford reactors were the first of several graphite moderated reactors. At least 25 such reactors have been built and operated and still more are planned. Most of these are research reactors, although the Hanford and "Windscale" (England) reactors are for plutonium production. The Calder Hall reactors (England) are dual purpose, i.e., for producing 42 Mw of electricity as well as plutonium.

The X-10 first went critical on November 4, 1943. It has a critical mass of 27,200 kilograms of natural uranium arranged in a regular lattice as shown in Figure 5. The fuel slugs are 1.1 in. in diameter and 4 in. long containing natural uranium clad with aluminum. These slugs are located in channels, arraged in an 8 in. square lattice, which pass through the graphite "pile." The graphite itself forms a 24 ft. cube having fuel located in an inner 18.5 ft. cube so that the additional graphite acts as a reflector. Since this is a research reactor in which neutrons are important rather than power output, it is possible to use a relatively inefficient coolant, specifically air, which absorbs few neutrons. The relative inefficiency is indicated by the fact that approximately 6500 lb/min of air are required to remove the 3.5 megawatts of heat produced. The Hanford reactors, based on the X-10 design, use light water to remove the much greater quantity of heat produced. The shielding of the X-10 is concrete 7 ft. thick. Control is exercised by 3 cadmium, 4 steel, and 4 boron-steel rods.

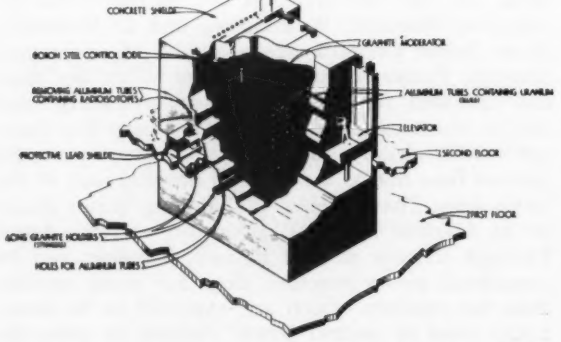

Figure 4. General Arrangement of X-10 Reactor.

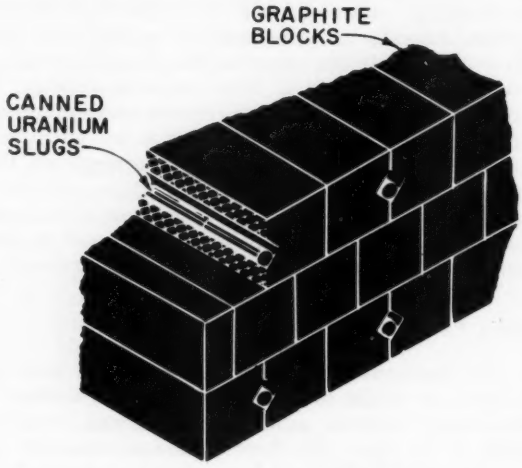

Figure 5. Graphite-Uranium Lattice of X-10 Reactor.

Swimming Pool Reactors

Graphite moderated reactors, in addition to historical importance, will continue to be an important class of reactors for sometime to come. From the viewpoint of research reactors, however, they leave something to be desired from the viewpoint of flexibility and are rather expensive (the X-10 cost over $5,000,000). A reactor which goes far toward overcoming these two objections is typefied by the Bulk Shielding Reactor (BSR), better known as the "swimming pool" reactor, which was built at Oak Ridge National Laboratory at a cost of about $500,000 and has proven to be the first of a class of reactors used for research purposes. The BSR allows considerable flexibility on both fuel loading and experimental apparatus arrangements.

The relative simplicity of the BSR is shown in Figure 6 as the reactor is simply a large concrete tank filled with water with the active core or lattice near the bottom. The reactor produces approximately one megawatt of heat which is dissipated throughout the water by natural convection. The fuel used is more than 90% U^{235} arranged in MTR type fuel elements. These fuel elements have 18 parallel plates arranged in a 3 in. by 3 in. by 24 in. element. The water which fills the pool serves as a moderator and as a shielding material, with a minimum depth of 17 ft. required for shielding.

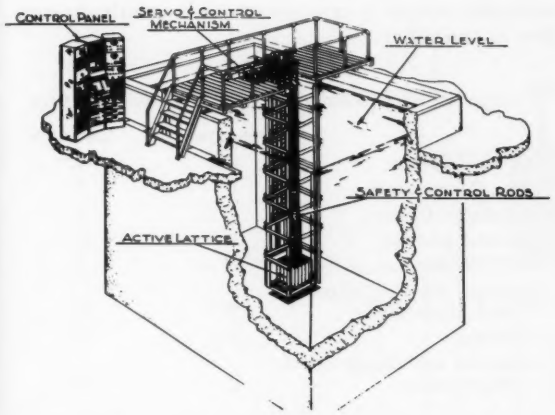

Figure 6. General Arrangement of Bulk Shielding ("Swimming Pool") Reactor.

Water can be used as a reflector or it can be supplemented by BeO. The critical mass for water reflection is 3.5 Kg which is reduced to 2.3 Kg using BeO reflection. Control is exercised through 3 B_4C rods and 1 type 347 stainless steel rod.

Power Reactors

Although nearly all of the reactors now in operation can be classified as research and development reactors, the development of cheap nuclear power and improved neutron economy (i.e., breeding) are valid aims, even if long term. It is toward these ends that many of the present research reactors are directed to determine the feasibility of large scale power reactors based on various systems.

Reactor technology is massive and expensive because it consists of a relatively few large devices and thus has rather limited possibilities for experimentation. Each reactor project resembles an inverted pyramid in that one idea requires a constantly increasing amount of work for its development so that only a few of the hundred-or-so possible reactor types can be seriously undertaken. The reactor experiment, using a relatively small scale reactor embodying most but not necessarily all essential features of a large scale reactor, has been accepted as a valid development device. This serves to decrease the expense and inertia of development. But there is so much inertia remaining that once a line of development has been chosen, it is extremely difficult to change course to another line.

This inertia is indicated by the preponderance of pressurized water type reactors in the United States. This is primarliy due to the great success of the reactor in the *Nautilus* which is perhaps the first real power reactor in this country. This type of reactor has been developed in the Army Package Power Reactor (APPR-1), in the pressurized water reactor (PWR) at Shippingport, Pennsylvania, and in several other proposed ship propulsion reactors. Liquid cooled reactors such as these (heterogeneous, solid fuel) tend to have lower capital costs because they are relatively small but have higher operating costs because of poorer neutron economy. Gas cooled reactor systems have higher capital costs but lower operating costs and are favored in England in preference to liquid cooled types because of lower fixed charges due to differences in the bookkeeping systems.

Liquid vs. Solid Fuel Reactors

A far more basic point of disagreement than type of coolant is the question of whether a fuel should be solid or liquid. This question is basically whether a reactor is a mechanical plant (solid fuel) or a chemical plant (liquid fuel). The essentials of these two systems are shown in Figure 7 for a boiling water reactor system which is the ultimate in a pressurized water system with solid fuel and in Figure 8 for an aqueous liquid fuel. These two types of systems can be compared for two practical cases of the Experimental Boiling Water Reactor (EBWR-1) at Argonne National Laboratory (Figure 9) and the Homogeneous Reactor Test (HRT or HRE-2) at Oak Ridge National Laboratory (Figure 10). We might note that Figure 10 indicates a breeder reactor which implies more ambitious aims than those of the EBWR. Actually, it is planned to

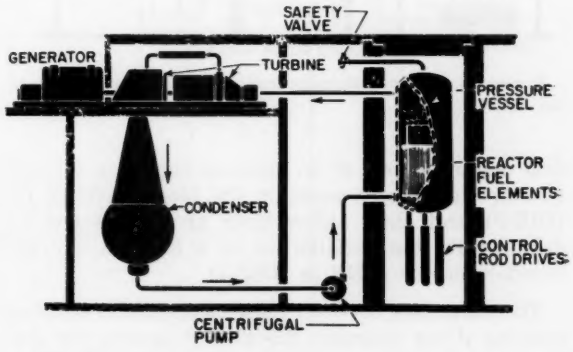

Figure 7. Simplified Boiling Water Reactor System for Power Production.

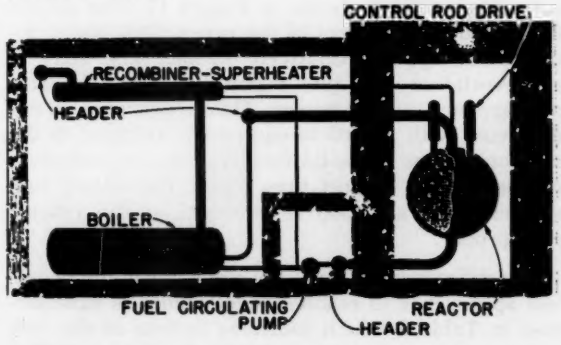

Figure 8. Simplified Aqueous Liquid Fuel Reactor System for Power Production.

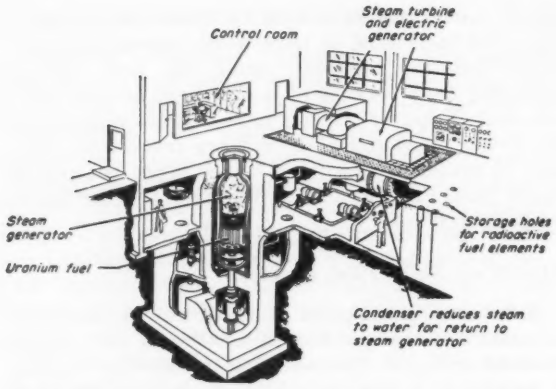
Control room
Steam turbine and electric generator
Steam generator
Uranium fuel
Storage holes for radioactive fuel elements
Condenser reduces steam to water for return to steam generator

Figure 9. General Arrangement of Experimental Boiling Water Reactor.

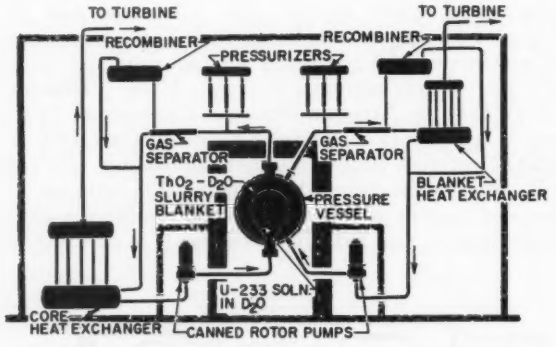

Figure 10. Aqueous Homogeneous Thorium Breeder Reactor System.

first operate a test of an aqueous fuel in a burner reactor with heavy water in the blanket (HRT or HRE-2) and then follow with an experiment to demonstrate the possibilities of a thermal, power, breeder reactor (TBR or HRE-3).

The difference between these two systems is more striking if we examine the flow diagrams for the Experimental Boiling Water Reactor (EBWR) shown in Figure 11 and for the Homogeneous Reactor Test (HRT) shown in Figure 12. The EBWR is the end development of the pressurized water reactor and appears relatively simple. The HRT is representative of a two region liquid fuel reactor and appears quite complex. This appearance is not deceiving with regard to equipment external to the reactor core as the solid fuel systems are definitely simpler in this respect than liquid, circulating fuel systems. The situation is reversed in the reactor core proper.

The difference between the mechanical and chemical approaches to reactor development is summarized in Table 2 which indicates factors in the two systems and rates them as relatively simple or relatively complex. We note that when a problem is relatively simple in one system, it is relatively complex in the other.

TABLE 2

Comparison of Solid and Liquid Fuel Reactors

	Solid Fuel	Liquid Fuel
External System	S*	C**
Core Construction	C	S
Reactivity Control	C	S
Material Control	S	C
Fuel Element Longevity	C	S
External System Longevity and Maintenance	S	C
Corrosion	S	C
Chemical and Metallurgical Reprocessing	C	S

To illustrate and clarify the differences between the two systems, let us consider each item in Table 2 separately.

External System: The liquid fuel system (e.g., HRT) has a much more complicated system than the solid fuel (e.g., EBWR) since control in liquid fuel systems is exercised by varying the fuel concentration which requires very strict control of fissionable material, in turn necessitating weigh tanks, evaporators, and fuel storage tanks which are absent in a solid fuel system. Since radiation causes dissociation of water into hydrogen and oxygen it is necessary to use a recombiner to form water in an aqueous fuel system. The liquid fuel system combines some continuous chemical processing of the fuel with reactor operation thus requiring a more complex external system. Even a simple process such as continuous removal of Xe^{135} requires a continuous gas-stripping and let down from high to low pressure thereby adding to the complexity of the system. Still further, there is a requirement of absolute leak tightness in liquid fuel systems due to radioactivity maintenance difficulties so that there must be a complete leak detection system. This same kind of complication occurs in a heavy water version of the EBWR but with less serious consequences in the event of a leak.

Core Construction: All solid fuel reactors have a forest of fuel elements and control rods. Liquid fuel reactors are essentially tanks (or double tanks) with little internal gear. The difference is quite striking if the core region of the EBWR (Figure 13) is compared with the HRT (Figure 14). We might argue about the simplicity of a double tank with an internal Zr core (HRT) but it is a fact that it was fabricated with greater ease than anticipated.

Reactivity Control: Liquid fuel systems have no (or very few) control rods since they rely principally on varying fuel concentration and density for control. All solid fuel reactors have control rods.

Material Control: This, of course, implies accountability for fissionable material. In a solid fuel reactor this is almost a matter of simple bookkeeping but is a definite problem in any liquid system with circulating fuel.

Fuel Element Longevity: This problem does not exist in the liquid fuel reactor but is one of the central problems in a solid fuel reactor. In a solid fuel system fuel elements are expendable and replaceable. In a liquid fuel system heat exchange equipment and the core are expendable and replaceable.

* S = relatively simple
** C = relatively complex

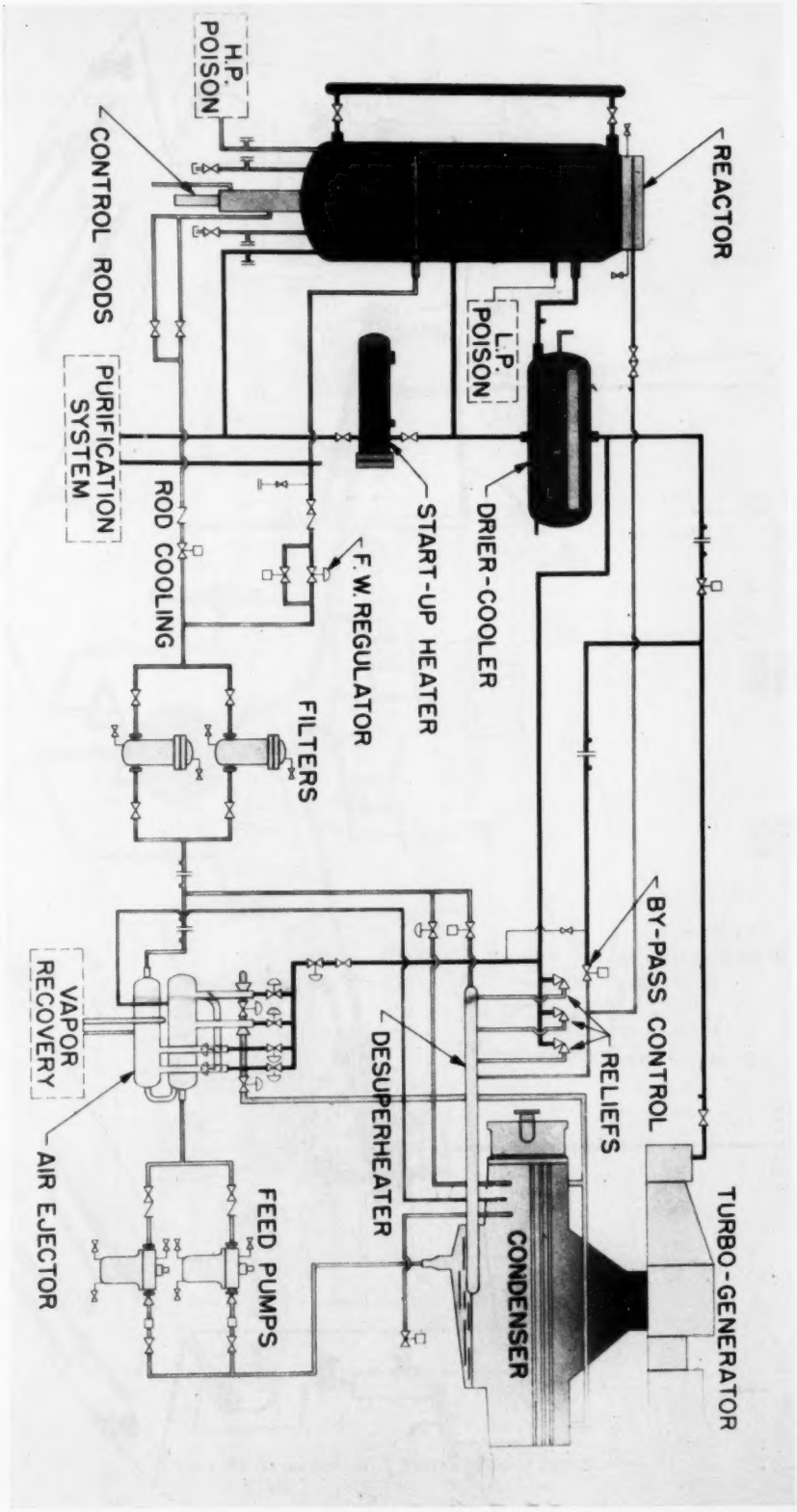

Figure 11. Flow Diagram for Experimental Boiling Water Reactor.

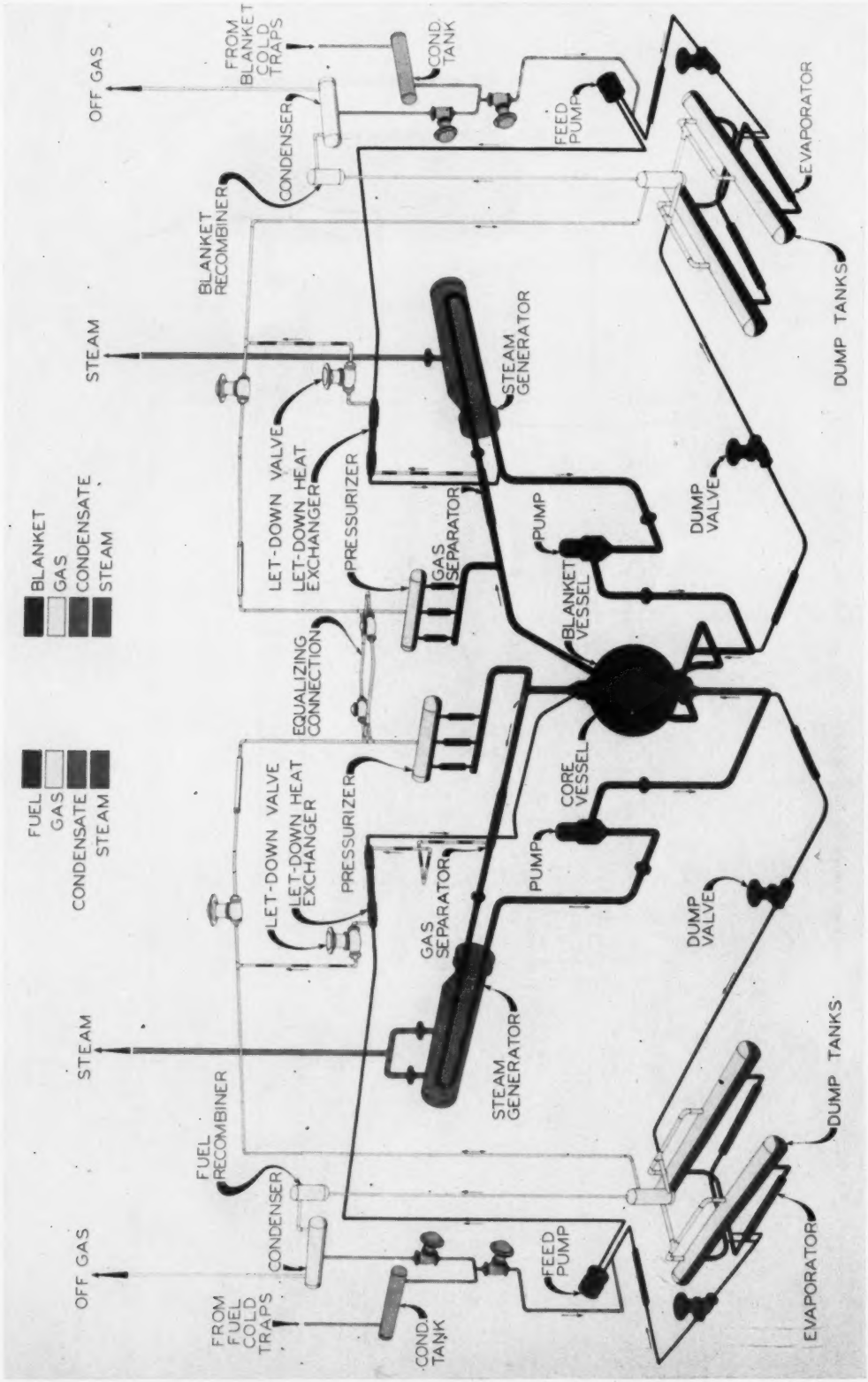

Figure 12. Flow Diagram for Homogeneous Reactor Test.

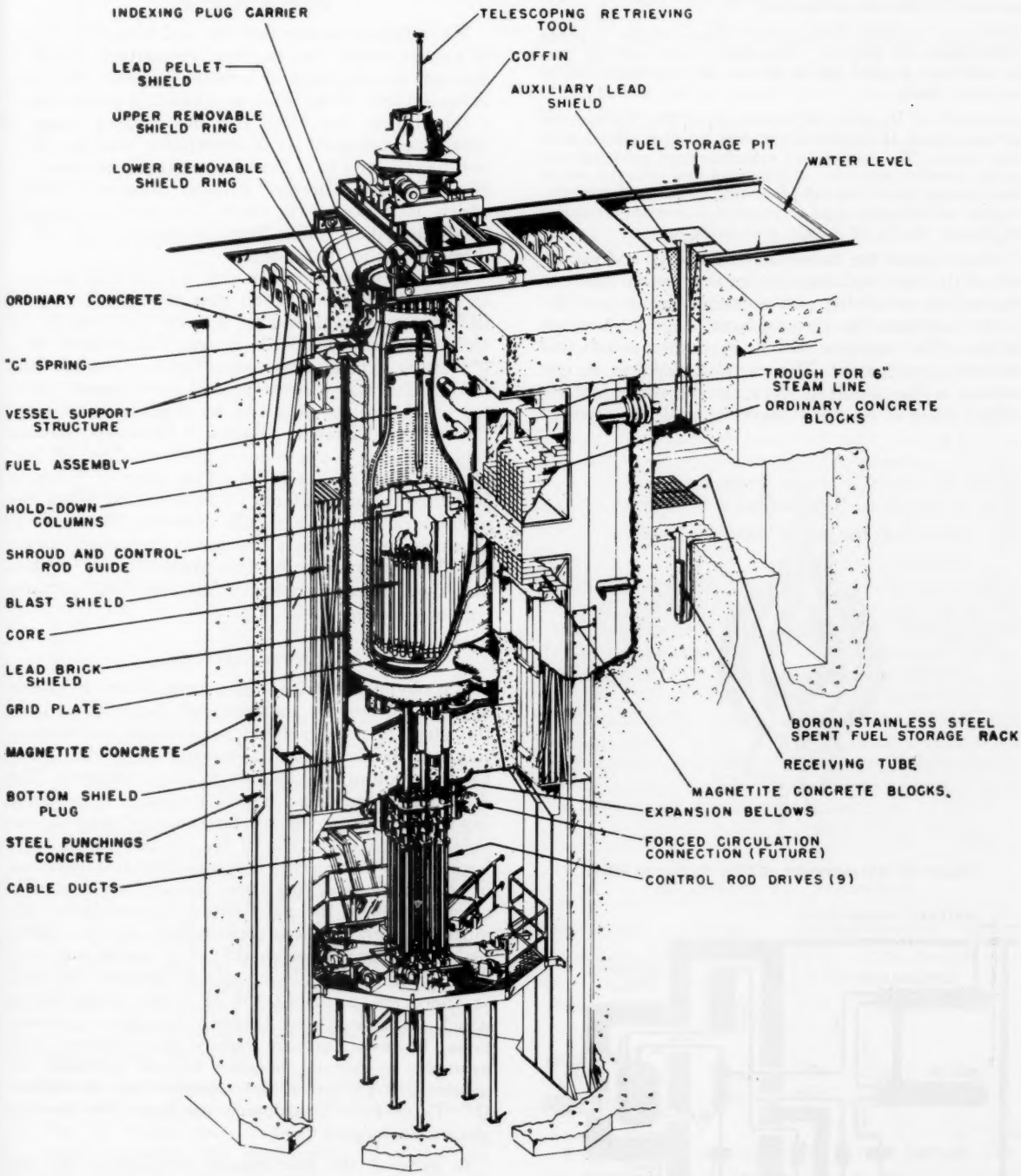

Figure 13. Arrangement of Core Region of EBWR.

External System Longevity and Maintenance: This is one of the major problems in the liquid fuel reactor principally because of radioactivity, corrosion, and the greater complexity of the external system in comparison with the simpler problem in the solid fuel reactor.

Corrosion: Corrosion is a problem in every reactor. In liquid fuel systems the problem is appreciably more complex than in solid fuel systems due to the use of more aggressive or corrosive fluids.

Chemical and Metallurgical Reprocessing: This is a problem in both classes of reactors but is more complex for the solid fuel system. The use of fuel elements requires dissolution of the element, separation of unburned fuel from the rest of the material, metallurgical processing of the fuel and fabrication of new elements. In liquid fuel reactors treatment of the fuel can be an integral part of the system.

In one sense the belief that reliability and economy of the heat exchange equipment can be made to exceed the reliability and economy of the fuel element motivates the development of liquid fuel reactors. The opposite belief motivates solid fuel reactor development. The complex problem in one system is the simple problem in the other system. Which class of reactor is superior will be answered only by the construction and operation of both types of reactor.

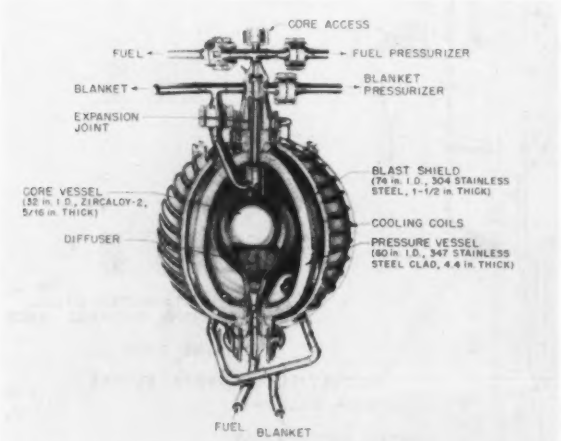

Figure 14. Arrangement of Core Region of HRT.

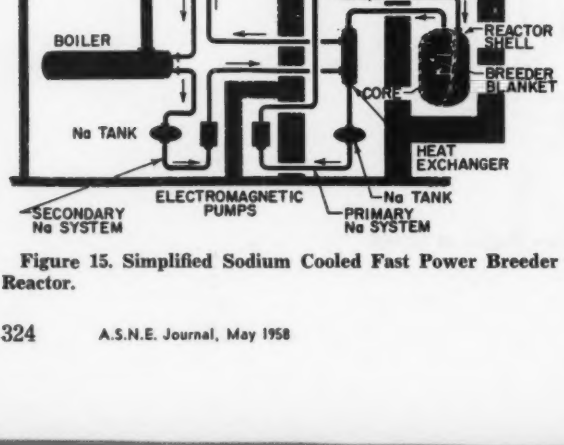

Figure 15. Simplified Sodium Cooled Fast Power Breeder Reactor.

BREEDER REACTORS

We indicated earlier that the real long range hope of nuclear power lies in effective neutron economy through development of breeder reactors. We also indicated that, in addition to producing power using a liquid fuel, the HRT has the goal of being a breeder experiment. It is anticipated that the HRT will be followed by a two-region reactor of about 60 Mw heat, the Thermal Breeder Reactor (TBR), which is expected to show a positive, although small, breeding gain. This, of course, will be a thermal, liquid fuel reactor.

It is also possible to breed in a solid fuel reactor. In fact, the demonstration that breeding was possible was accomplished in a solid fuel reactor in 1951. This reactor (EBR-1) was fueled with 90% U^{235} using natural uranium as fertile material. This fast reactor was a research and development reactor which will be followed by a power prototype, Experimental Breeder Reactor-2. This fast, sodium cooled reactor is expected to produce about 60 Mw of heat. The fuel will be about 50% U^{235} and a breeding factor of about 1.2 is expected using depleted uranium as a fertile material. The general arrangement of such a reactor is shown in Figure 15. This fast reactor has no moderator, of course, but does have a reflector of depleted uranium eighteen inches thick.

FUTURE REACTORS

It is obvious that, for a long range future in power applicators, breeder reactors must be developed. At this stage in the development of reactor technology it would be foolhardy to attempt to predict what future reactors will be like in other respects. The difficulty of prediction is well illustrated by estimating the number of reactor types which are conceivable. Table 3 lists some of the choices which must be made by the reactor designer. The total number of combinations of just these choices, which are by no means all of the possibilities, is over 3000! Admittedly many of these combinations are not sensible, e.g., a fast reactor would not be cooled with any fluid which also would act as a moderator, but even so there are probably 100 or more combinations which initially appear feasible. Nuclear considerations, however, greatly reduce this number. For example, a thermal breeder almost certainly requires U^{233}-Th but a fast breeder can use either U^{233}-Th or Pu^{239}-U although the latter has the nuclear advantage.

In general, the best reactor complex is the one which operates at the greatest thermal efficiency. In each reactor there is a certain amount of relatively expensive material, fissionable material and/or moderator, which represents a continuing expense and it is desired to extract as much energy as pos-

TABLE 3—*Some Reactor Design Alternatives*

A. Fuel
   1. U^{233}
   2. U^{235}
   3. Pu^{239}

B. Fertile Material
   1. Th^{232}
   2. U^{238}

C. Neutron Energy
   1. Fast
   2. Intermediate
   3. Thermal

D. Geometry
   1. Heterogeneous
   2. Homogeneous

E. Fuel Matrix
   1. Solid Fuel
   2. Liquid Fuel

F. Coolant
   1. Gas
   2. Liquid Metal
   3. Molten Salt
   4. H_2O
   5. D_2O
   6. Hydrocarbons

G. Moderator
   1. H_2O
   2. D_2O
   3. Be
   4. BeO
   5. BeC
   6. C
   7. Hydrocarbons

sible from a given amount of fuel. The amount of electrical energy extracted per unit amount of expensive material might be called a "material efficiency." High thermal and material efficiencies lead to low cost power, but are not always found together. For example, a water moderated U^{233}-Th thermal breeder might operate at a thermal efficiency of 20% and 10,000 kw per kg of U^{233} while a liquid metal cooled fast breeder might operate at a thermal efficiency of 35% but only 1000 kw per kg of Pu^{239}. The material efficiency is thus 2000 kw per kg and 350 kw per kg, respectively. It is entirely possible that this disparity in material efficiencies could offset the economic advantage of high breed-gain (i.e., high neutron energy) and high thermal efficiency in the fast system.

Since the breeding gain of the fast reactor is higher than in the thermal reactor, and both the U^{233}-Th and Pu^{239}-U cycles can be used for fast breeders, we might question the desirability of a thermal breeder using the U^{233}-Th cycle. One reason, of course, is the greater material efficiency of the thermal breeder. The other reason is that any diluent in a fast reactor tends to decrease neutron energy and thereby cause a reduction in breeding gain. Diluents are of three kinds: structural material, coolant, and fertile material; with fertile material being most effective in depressing the neutron spectrum. On the other hand, we desire a large proportion of fertile to fuel atoms to have a longer time of operation before serious radiation damage occurs and reprocessing is required. The high breeding gain tends to offset the economic effect of expensive reprocessing of the fuel.

The advantages of the liquid fuel systems (relatively simple chemical processing, good heat transfer, and good nuclear control) must be weighed against the problems of corrosion and containing the radioactivity released by fission. The solid fuel system has the advantages of less serious corrosion and relatively secure containment of radioactivity which must be weighed against the number of chemical and metallurgical reprocessing cycles required. For thermal breeders, liquid fuel systems have considerable advantage over solid fuel systems. The sole nuclear advantage of solid fuel systems is a higher fast fission effect which can be achieved only by very close lattice spacing and a high ratio of fertile material to fuel. The close packing implies a more difficult engineering problem in effective removal of heat.

Whether one reactor type is superior to another, we simply do not know, although it appears quite likely that thermal breeders based on U^{233}-Th and fast breeders based on Pu^{239}-U will develop into acceptable reactor types. These may well be in a variety of forms, of which the most promising for power production are given in Table 4. Which one reactor type is best will be indicated only after much additional work has been done. It is fortunate that the answer to this question is being sought with so much diversity in so many countries.

TABLE 4—*Promising Reactor Systems for Industrial Power Production*

Reactor Type	Fuel	Fertile Material	Moderator	Coolant
Sodium-Graphite	1-2% U^{235} or U^{233}	U^{238} or Th	C, Be, BeO	Na
Pressurized Water	Slightly Enriched U	U^{238}	H_2O	H_2O
Pressurized Heavy Water	Natural U	U^{238}	D_2O	D_2O
Fast Breeder	Pu	U^{238}	None	Na
Aqueous Homo. Breeder	U^{233} Soln.	Th	D_2O	U^{233} Soln. in D_2O
Non-Aqueous Liquid Fuel	U^{233}	Th	Graphite	Fused U Salt or Liq. Metal Solution

Official U. S. Navy Photograph

USS *Forrestal* (CVA-59) and the USS *Des Moines* (CA-134) refueling from the USS *Severn* (AO-61) while operating with Task Force 26 in the Atlantic

EDWARD J. ENGORON

MAINTAINABILITY

ACKNOWLEDGEMENT

This is a slightly abridged version of an address given before the Electronic Industries Association Conference on Maintainability of Electronic Equipment, The University of Southern California, on 18 December 1957. The author is Mr. Edward J. Engoron, Director, Maintenance Engineering, Office of the Assistant Secretary of Defense (Research and Engineering).

THE FUTURE quite often becomes the present much more quickly than we anticipate. This is particularly true in the field of electronics where uncommon inventiveness and productivity have brought forth an almost endless variety of devices that have affected our living today, and upon which we are so dependent that there will be a tomorrow.

The "black boxes" symbolic of, and identified with, electronics are not as innocuous as they appear. In fact, to many of us, they seem a modern "Pandora's Box"—releasing, when opened, all the human ills. You may recall that "Hope" was also contained in Pandora's Box—and did not escape. Fortified with a speaker's traditional license for analogy, I submit that maintainability is the "Hope" of our black boxes.

In a sense, getting people together to discuss maintainability is somewhat like Thomas Edison's experience with the peep shows he first produced in 1889. In order to see the little show, a penny was put into the slot and one looked through a small window at a pint-sized movie which lasted a quarter of a minute. Edison had four different films the audience could see: "U. S. Battleships," "Rip Van Winkle," "Ballet Dancer," and "Girl Climbing An Apple Tree." On the opening day of the peep show, only 25 people paid to view "U. S. Battleships." As you might expect, 365 people took a look at the "Girl Climbing An Apple Tree!" In the main, except for we who have to live with it, maintainability probably is the equivalent of the Battleship film.

When I was planning this talk, I decided early that there were three things it definitely would not be. It would not be a technical talk, because the Panel Sessions will discuss the technical areas much more competently than I could. It would not be basically a critical talk, because so much good work has been done; and it would not be a congratulatory talk, because so much good work is yet to be done.

It appeared to me that the contribution I could best make to this Conference was threefold. First, to provide background that would make clear to all the need for continued dedication to achieving better maintainability; second, to express the maintainability concepts and convictions held by my Office; and third, to indicate, generally, where effort is required by both Industry and the Department of Defense to make the concepts and convictions a reality. Tennyson once said: "Charm us, orator, 'til the lion looks no larger than the cat." I shall not follow Tennyson's advice, nor do I propose to try to make the cat look like a lion—it is a large enough, difficult and predatory animal as is.

In looking at the excellent program that the Planning Committee has put together for this Conference, it is obvious that the issues are not controversial ones. Certainly the level and breadth of Industry and Military representation, and the variety of maintainability aspects to be discussed, indicate that no one is "agin" maintainability. This, of course, is pleasing to all of us in the Department of Defense who contribute in some way to the main-

tenance of our weapons and equipment. While it appears that none of us are "agin" maintainability, it is conceivable that there are significant differences in how we should be "for" maintainability. A little later in my talk I will state our views on this subject. Before doing so, I think that it would be helpful to sketch briefly the background that has caused this genuinely needed attention to maintainability.

I would like first to ask you to look back with me about 25 years—or about 10 years before World War II. At that time, and up until our entry into the War, we had great stability in our military personnel and in the weapons they used and maintained. This enabled us to keep up quite well as technology advanced. With the build-up toward World War II, and the magnitude and tempo of the War, large numbers of advanced, complex equipments were produced and put into the users' hands so quickly that our maintenance technician capability could not match the pace. However, at about the time the War ended we were almost on top of the problem.

With demobilization, we held on to only a small part of the skills developed and trained during the War. This would not have been too serious except for two events that occurred. First, we entered the "jet age"—and by this is meant much more than jet propulsion for aircraft. The "jet age" includes the multiplicity of complex equipment that the performance attainable through jet propulsion—and other advances—made mandatory for development and use. We were starting to gain on this problem when the Korean War came along. This event, of course, led to a rapid expansion of the Military Establishment and generated, once again, many "crash" programs. These programs frequently resulted in the introduction to service use of weapons and equipment that had not been adequately engineered or service tested prior to production. We were gaining on this problem when the Korean War ended and an extensive demobilization liberated the maintenance skills we had again so painfully and expensively developed and trained.

Since the Korean War, the world situation has made necessary the continuation of high rates of development and introduction of new weapons and equipment. The performance we demand of these new weapons probably cannot be achieved without great complexity. I know complexity needs no further exposition from me, since all of us here have had it illustrated so many times in terms such as increased engineering man-hours used to develop a product for production; or maintenance man-hours required to support an hour of flight; or recurring support costs compared with initial costs; or numbers of vacuum tubes used in electronic systems, etc.

Unfortunately, the prevalence of complexity in all kinds of weapons and equipment, even when accompanied by reasonably high orders of reliability, makes a tremendous demand for maintenance resources of all kinds: Skilled manpower, money, facilities, and spare parts and test equipment. Some idea of this demand for resources can be obtained from these few key statistics we use in illustrating the magnitude of the Department of Defense Maintenance Engineering job.

We are maintaining a weapons and equipment inventory valued in excess of 110 billion dollars. To do this, we have, throughout the world, more than 21 thousand buildings of various kinds comprising in excess of 250 million square feet in which more than 800 thousand military and civilian maintenance technicians do their daily work. We have had to buy and have on hand maintenance spares and spare parts that cost more than 20 billion dollars. On an annual basis, maintenance of our weapons and equipment costs the Department of Defense more than 7 billion dollars—or 20 million dollars each day.

Despite these great expenditures, our maintenance is not as effective as it should be. To us, maintenance effectiveness, in its simplest terms, means that a weapon or item of military equipment is ready to do its job adequately at the time it is required. Today, too many of our weapons are too often in the hands of maintenance people when they should be in the hands of the operators and users. Obviously, maintenance should be the means of achieving greater use of equipment, not a detraction from it. Our future maintenance effectiveness will be improved significantly only as we are able to improve maintainability.

Gentlemen, this is the backdrop against which we look at maintainability and which, inevitably, influences the development of our concepts and convictions. I do not expect that you will agree completely with these convictions, nor do I believe that it will be a simple matter to translate these convictions into approved policies and active programs for accomplishment. Each conviction, to become a reality, requires varying degrees of effort by all of us—Industry, the Military Departments, and the Office of the Secretary of Defense. Some of these efforts must be made in concert—others can be undertaken unilaterally. Some of these efforts must be delayed until other efforts have been completed. During the next several months, we expect to work more closely with the Military Departments and Industry on these efforts. In all cases, the work to be done will relate to our convictions, which I would like to tell you about now:

Maintainability can be defined: The definition most commonly used states that: "Maintainability is a quality of the combined features and characteristics of equipment design which permits or enhances the accomplishment of maintenance by personnel of average skills, under the natural and environmental conditions in which it will operate." There is more than a semantic problem with this definition. We must define maintainability more precisely—perhaps by major commodity or equipment category areas—and indicate the applicability of the definitions to specific levels of maintenance. Once we have developed such definitions, they should

be used to the maximum so that all communication among all of us can be loud, clear, and ungarbled.

Maintainability can be improved: This is not intended as an "agin sin" statement. We must guard against any feeling of complacency that we have mastered the problem, even for a specific item of equipment. Hardly any weapon is used for long without modernization which frequently raises new maintainability problems. Also, even cursory examination of similar products made by different producers reveals variances in maintainability ingenuity. By continuing and increasing the frequency of the exchange of non-proprietary information, we can help each other with problems, to our mutual benefit.

At least equal in importance to the exchange of non-proprietary information, is the need to improve communications between designers and the maintenance elements of the Military Services. The Military Services must make their requirements and limitations known to the designers so that they can understand the importance of maintainability to successful military operations. The next generation of military weapons will show little improvement in maintainability unless this communication takes place—as early as possible and with adequate frequency and detail.

Maintainability is measurable: The fundamental elements upon which maintainability can be judged are: Time, Skill, Effort, and Materials. We should be able to predetermine accurately the recurring maintenance tasks; how long it takes to accomplish these tasks; how many of what kinds and levels of skills are needed; the special tools and test equipment associated with these tasks; and the spares or parts that will need replacement at stated intervals. Until this is done, equipment maintainability can never be more than a pious plea in a military specification, or a well-rounded phrase in a sales brochure.

Maintainability can be specified: As unwelcome as this conviction may be to some, we will obtain genuine maintainability, consistently, only when what we need is reduced to finite terms and is incorporated into specifications against which procurement contracts are awarded. We must, together, find how to better specify maintainability in terms that will assure that the Services receive military products possessing the maintenance characteristics they need; that imaginative design is not inhibited; that performance and productibility are not detracted from significantly; and that the development and production cycles are not lengthened appreciably.

Maintainability is worth paying for: Maintainability is a tangible asset when achieved in a product, and a liability when lacking. The additional one-time cost for incorporating genuine maintainability into equipment is insignificant when compared with the recurring total cost in skills, numbers of people, training, and dollars for the continuing support of equipment with poor maintainability characteristics. We must campaign actively to gain more acceptance and recognition of the fact that good maintainability means increased readiness of our Military Forces—and readiness is still considered the primary deterrent to war. Important as readiness is, other benefits stem from maintainability. These include: Reduced time for maintenance, which increases the availability of equipment for use; better utilization of maintenance and other personnel; decrease in the numbers and skill levels of maintenance personnel required, with consequent reduction in training requirements and costs.

Genuine maintainability is not only worth paying for, it can be paid for when we demonstrate that improved readiness will result, and effort and dollar savings will be realized.

Maintainability is a design parameter: A general maintainability concept can be developed during the preliminary design phase for new equipment. In any event, specific maintainability characteristics must be incorporated not later than during the prototype design phase. Most of us are now in agreement that: "Maintainability cannot be 'built in' during the production cycle, nor can it be 'inspected in' at the end of the line." In order to assure that maintainability is designed into the product, we must make it easier for Industry designers to avail themselves of opportunities to observe and investigate military maintenance operations and the factors that limit and impede more effective maintenance in the field.

Once designers have had sufficient exposure to the problems of maintaining equipment in its operational environment, we will more quickly attain our objectives. One of these is designing for maintenance job simplification commensurate with the level of technical knowledge, skill and experience of our military technicians. Another is design for maximum speed of work accomplishment—or minimum down-time—of the equipment being maintained. We could also expect the development of maintenance technical data, training aids and training courses which will be completely suitable and easily understood at the technician level intended to perform the maintenance required.

Maintainability can be taught: Our next generation of designers and engineers, now in college, is the most valuable asset we have for assuring maintainability in weapons and equipment of the future. In addition to "education by exposure," our engineering and technical curricula should teach the embryo engineer how to design for maintainability. This will rapidly become as much the engineer's stock in trade as his technical library and slide rule. Also, post graduate work slanted toward maintainability should be encouraged.

We should stimulate our technical schools to solicit guest lecturers competent to discuss maintainability, and arrange for student engineers to see the operation and maintenance of military equipment in its planned environment. Indoctrination of newly hired designers and engineers should emphasize the objective of producing a maintainable product and include, on a selective basis, a short term assignment with the field service unit. Additionally, we must do more "missionary work" with the many people, other than design and maintenance engineers, who have a loud and authoritative voice in approving equipment design, and in releasing the equipment to production.

Maintainability can be organized: Organization is the means through which we achieve extraordinary results from ordinary people. The consistently good examples we see of maintainability are developed, both in Industry and the Department of Defense, where the importance of the maintainability function has received organizational recognition. In most cases, all that is required is a small, competent group charged with concentrating on and dedicated to improving maintainability. Such a group must understand both the Military Services and Industry problem. Since the concepts they develop must find acceptance by design engineers, the maintainability group should be manned primarily with design engineers who have had field service experience.

Maintainability is essential to reliability: This conviction is not as paradoxical as it sounds. Our inventive genius, as well as that of our potential enemy, makes it extremely unlikely that we will ever possess both the resources and technology to build weapons that can sit unattended for many years, and then perform perfectly when called upon. Maintenance is inevitable. In fact, once weapons have been produced, the maintainability designed into them provides the only means of assuring that reliability degradation stays within tolerable limits.

To these specific convictions on maintainability, I would like to add some equally important general ones. While maintainability must include "accessibility," accessibility, per se, is not maintainability. Certainly accessibility is an important requirement in many cases, but the mere fact that a technician can "get at something" does not mean that he can maintain it.

I have observed also, with some concern, a

tendency to try to reduce maintainability to mathematics. I do not want to deprecate this work—it is important to our general understanding of maintainability, and may contribute significantly to measuring maintainability. However, what we must do more of is to reduce maintainability to "humanics." By this I mean maintainability design for the humans we actually have doing the work, rather than those we would like to have doing the work. These humans who maintain our weapons and equipment are not uniquely qualified by aptitude or prior-to-service education in maintenance. This fact is of primary importance in designing for maintainability. Let me illustrate: Practically all of our direct support maintenance—organizational and field level—is accomplished by military technicians—some 600 thousand of them. Only 55 out of each 100 of these technicians have graduated from high school. Slightly less than 3 out of each 100 have graduated from college. This is the formal educational level for which maintainability must be designed.

In addition to this unhappy circumstance, which doubtlessly will continue, we can take no comfort in thinking that educational deficiencies will be off-set by in-service training. This might happen if the people stayed in service, however, while re-enlistment rates for first termers have improved for the last three years, today only 16 out of each 100 electronic technicians re-enlist. The situation is only very slightly better in other maintenance technician skill areas. Consider, if you will, both the educational level and turnover rate and I am confident you will agree that many preconceived and academic notions about designing for maintainability warrant our most critical review. We can use mathematical and theoretical solutions to maintainability—but we need empirical ones too.

Gentlemen, I hope that I have dispelled any doubt that may have existed as to the need for even more vigorous and imaginative work on maintainability; and have communicated adequately our views on the subject. The Department of Defense, with a mission of serving as a deterrent to war, and instant readiness should we be called upon, has a very high stake in the success of this work. We are putting major effort in the development of sound maintainability policies. When approved, we intend to see them converted into operating programs. We must specify to Industry, more precisely, what we want in maintainability—and we have to be willing to pay for maintainability that genuinely enhances readiness of our weapons and reduces our recurring costs.

While Industry has compiled a fine record of unselfishly motivated and voluntary effort to improve maintainability, I think Industry recognizes also that it has a "good business" stake in maintainability. Henry Dreyfuss, the prominent industrial designer, said: "When the point of contact between the product and people becomes a point of friction, then the designer has failed." Maintainability—or lack of it—can easily become the point of contact that generates friction. That potential point of friction, more than ever, is of great importance to Industry. The financial facts of life are such that the selection of one weapon over its competitors is more often being decided by our ability to operate it reliably, and to maintain it effectively, within both our financial and technical resources. We expect this trend to continue and to receive much greater emphasis in future Department of Defense procurement programs.

Industry need not mark time while we are doing our job. I urge you to exploit the excellent work that has been done to date; to foster new and more imaginative effort; and to organize for maintainability. I ask also that you disseminate within your organizations the background I have tried to furnish —it can help your design groups in coping with the enormous problem they face.

For all of us, both in Industry and the Department of Defense—present company excepted!—I caution that we not make the mistake of talking the subject to death. This is my cue to close and I will do so, stressing again one thought: Maintainability is maintenance ability—and no matter how outstanding the performance potential of a weapon, that potential is degraded significantly—and perhaps negated completely—if it cannot be maintained by the kind of people we have, in the environment in which it must be used. If we don't design equipment with this knowledge uppermost in our minds, we will be permitting hope to triumph over experience.

MAN AND HIS THERMAL ENVIRONMENT

ACKNOWLEDGEMENT

Reprinted from the November 1957 edition of "Mechanical Engineering" this consists of abstracts from six papers presented before the June 9-13, 1957 meeting of the American Society of Mechanical Engineers in San Francisco. Authors are as follows:

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Part VI—J. R. Hinshaw of the University of Rochester.

I—FACTORS IN HEAT STRESS

IN PHYSICAL terms, a man is a body which generates heat by metabolism. This heat is mostly dissipated at the skin surface, although some energy may be utilized in doing mechanical work and some is dissipated from the lungs. In general, if the amount of heat generated exceeds that dissipated from the skin, the man becomes warmer; if it is less than the heat loss, the man cools. The strain on the man from any environment will depend largely on this fact, and methods of estimating heat loss from the skin are a necessity before progress can be made.

The skin can be treated as a heated and generally moistened surface which is losing energy to the surroundings by convection, radiation, and evaporation. Heat transfer, as considered in most standard textbooks, consists of conduction, convection, and radiation. To these three must be added evaporation since it is an important factor in dealing with man's heat exchange. Any heat transferred by conduction from a surface to air is eventually carried away by movement of the air, and the whole process of conduction and convection is, for the purposes of simplification, termed convection.

(The authors develop equations to express the energy exchanges in terms of: convective heat transfer, net radiative heat transfer, evaporative heat transfer, convective coefficient, radiative coefficient, evaporative coefficient, surface temperature, air temperature, mean radiative temperature of surrounding objects and surfaces, water vapor pressure of surface, and water vapor pressure of air. From these equations it is shown, for example, how to calculate the temperature and humidities at which man can maintain thermal equilibrium when he must lose a certain number of Btu/sq ft./hr from his skin).

In the human problem, two distinct conditions can occur. The first of these is where all secreted sweat is evaporated, hence it is called the "dry-skin" condition. Here the amount of evaporative cooling is determined by the amount of sweat secreted and not by how much moisture can be evaporated by the air. If air temperature is above skin temperature, heat is gained by convection. The higher the wind speed, the greater will be the heating effect. Typical examples of such conditions are the desert environment with its hot winds, or the hot-air blasts found in some industrial plants.

The second condition is one in which sweat secretion is high enough so that all of it is not evaporated and some drips off. In these circumstances, cooling is not limited by sweat secretion but by the ability of the environment to evaporate the sweat. Accordingly, sweat-secretion rate bears no relation to evaporative cooling. Under such conditions an increase in air vapor pressure decreases heat removal by evaporation, while an increase in wind speed increases it. Thus a fan provides relief on humid days by increasing the potential for evaporative cooling.

EFFECT OF CLOTHING

The discussion has dealt with heat exchange between an uncovered surface or skin and the environment. The basic equation will apply to the clothed man if the coefficients of convection, radiation, and evaporation are modified. The convective heat-transfer coefficient for the so-called "still air layer" over the surface is changed to one for clothing plus air. The radiation coefficient must be reduced since clothing acts as a radiation shield. The evaporative coefficient also must be adjusted to correct for differences between the moisture permeability of air and clothing. Since, in general, clothing will have a lower permeability to moisture than a still air layer of equal conductivity, a coefficient of moisture resistance to vapor transfer is included in the general equation.

Variations in air movement, skin temperature, and sweat rate over different areas of the skin surface lead to a very difficult and impractical mathematical treatment. It is, therefore, necessary for the biotechnologist to use the best physical analysis available as a basis for his reasoning, modify his results somewhat using laboratory data, then add his skill and judgment to obtain a good reliable index.

II—THE BODY AS A HEAT EXCHANGER

The human organism differs from other heat exchangers in that its heat-regulation reflexes may be said to be a servomechanism with a complicated yet consistent method of responding to heat or cold stress. The nature of this patterned response is such that, in contrast to inanimate heat exchangers, the following properties of the human heat exchanger may undergo complex interrelated alterations over even a small range of ambient temperatures (area 70-90° F):

(a) Heat input to the exchanger.

(b) Alteration of the conductance of the peripheral material of the exchanger.

(c) Alteration of the total conductance from surface to ambient surround.

(d) Shift of heat-dissipating load from a low surface-volume ratio exchanger segment (the trunk) to a segment of higher relative surface (extremities).

(e) Conversion of the surface process of the exchanger from a dry-heat transfer to a combined dry-heat and evaporative process.

It has been necessary to make calorimetric studies of the human heat exchanger by use of the classical heat relations. It must be obvious, however, from an inspection of the servoproperties that a large amount of physiological study is required if an engineer desires to apply the classical relations to an immediate problem. He must be able to decide what the control state of the human heat servomechanism is for a particular ambient condition or a particular state of work stress in the organism.

This difficulty becomes clear from the following classical heat-exchange relations for the human body. In making this inspection the question may be asked as to how one proceeds with the computation, taking due account of the features of heat-exchanger behavior noted $(a - e)$ as continuously varying properties of the experimental object.

Radiation Exchange

The equation for heat transfer by radiation between the unclothed human body and the environment is given by

$$H_R = 1.37 \times 10^{-11}(T_s^4 - T_c^4)tAf\varepsilon, \text{ kg cal/hr} \quad (1)$$

where T_s = average skin temperature (deg. C

TABLE 1—*Mean[a] Values of Calorimetric Data, Mature Male Subjects, Normal Clothing, Seated Posture*

	Skin temp.	Air temp.	Radiant temp.	Operative temp.[a]	Metabolism	Evaporation
Mean	85.25	49.02	71.52	61.61	91.55	−20.86
Std deviation	3.26	10.70	16.15	10.17	7.72	5.70
Population[b]	180	180	180	180	180	180

[a] Operative temperature resembles in principle the process of reducing a gas to a reference volume and pressure. It may be understood in a sensory sense as the temperature of an enclosure with walls and air at the same temperature, and with an air movement of 15 to 20 fpm, with relative humidity of 50 per cent.

[b] Each item in the population is an exposure to a given calorimeter combination of air and radiant temperature for 3 hr.

Note: Temperatures, deg. F; metabolism and evaporation, kg cal per hr man; avg height 180 cm; avg weight 70.8 kg; avg DuBois surface area 1.76 sq meters; avg radiation area 1.34 sq meters.

+ 273), T_c = average radiant environmental temperature (+ 273), t = seconds in one hour, A = DuBois surface area, f = ratio of effective radiating surface to the DuBois surface area (0.78 for the unclothed adult in recumbent position), and ε = emissivity of the environment.

Conduction Exchange

Clothing and other factors normally reduce human conductive heat to a small fraction of the total exchange. However, the familiar classical equation is frequently applied to the problem of computing the alteration in the conduction of heat from the interior of the body to the surface.

(The author then develops equations for *heat loss by convection* (some degree of forced convection is generally present in human heat exchange) and for *heat loss by evaporation*, a variable of wide range in the biological heat-exchange process).

THE DESIGN SITUATION

The most frequent engineering requirement involving human heat loss requires the estimation of a resultant skin temperature regarding the problem of heat tolerance. Such design situations are generally too unusual to be settled by reference to data for the circumstances obtaining in ordinary air-conditioning problems. In other instances the problem is to estimate the stress effect of an increase in the radiant temperature of an environment, or to estimate the highest level of activity (heat input) consistent with fixed environmental heat effects.

In all such instances, a linear multivariable equation, permitting values to be fixed for four of the chief variables with solution in terms of a remaining variable, is of great usefulness.

The calorimetric log of human heat-exposure experiments of the author and associates at the Pierce Foundation Laboratory of Hygiene has been abstracted for the basic data of such a computation. In 180 calorimeter experiments on mature, normally clothed male subjects, the mean values of Table 1 were found for the group of 3-hr exposures. All of these experiments were under conditions which do not stimulate positive sweating.

The mean values given in Table 1 represent 180 numerical values distributed among six variables. To express these 180 values in a single equation requires the determination of the regressions between every possible combination of the six variables. Since operative temperature is derived from air and radiant temperature, the calculation program was reduced to one dealing with the five remaining variables. The Pearson product-moment method was applied to determine the 10 least-square solutions existing in the system of variables. From these intercorrelations the four partial regressions were determined, representing the relation between four pairs of variables with the influence of the remaining three variables removed mathematically.

This is a tedious operation and time-consuming, but the end result is very efficient in that it enables us to derive the following five-element equation from which the entire table of 180 data entries may be regenerated with surprisingly small deviation between the values of the regenerated table and the actual observational data from the calorimeter.

$$X_1 = 0.286X_2 + 0.142X_3 + 0.105X_4 + 0.092X_5 + 53.39$$

$$(T_S) \qquad (T_A) \qquad (T_W) \qquad (M) \qquad (E) \qquad \ldots\ldots\ldots\ldots (2)$$

where T_S, T_A, T_W refer, respectively, to mean skin surface, air, and wall temperatures, and M and E to metabolism and evaporation. In solutions of the equation the units of the variables as given in Table 1 must be used.

Equation (2) may be applied accurately to any seated-activity situation in which the crude average of air and radiant temperatures is between 50° and 80° F and with air movements of the order of 10 to 20 fpm, with occupants wearing normal male attire, or approximately seven pounds of clothing. In the absence of separate measurements of air and radiant temperature, or in the presence of air movements up to 100 fpm, it may be applied with approximate accuracy. In this latter case the reading of a black globe thermometer should be used to estimate T_0 (the combined T_A, T_W) effect, and the reading of this instrument substituted in both the T_A and the T_W terms of the equation.

III—REACTION TO EXTREME HEAT

Outside a limited near-comfort range, exposure to heat and cold leads eventually to body damage. The threshold of this injury is generally set by pairs of time of exposure and of body temperatures reached. We consequently find a relationship of safe exposure time or no-damage time and outer environment. Conditions of personal climate, then, do not fall into bearable and unbearable ones but into those bearable indefinitely, or for life, and into those bearable for a certain time, which may range from microseconds to a few years. The human behavior, physiological as well as psychological, resembles rather a chemical rate process with a certain critical margin than a physical process, such as fusion, which does not depend on time but on temperature and pressure only.

Peripheral blood circulation, shivering and muscular activity, and sweating are the main means the body employs to fight effects of cold and heat. All three regulants, temporarily or permanently, may be missing. It is roughly known how they act in a normal man if a certain environment acts for a certain time. All three need time to achieve their goal fully. Exposure to extreme conditions then indicates

that these three factors have not been activated before.

Prediction of safe exposure time is of practical interest. Since individual health, sweating, circulatory, skin and other functions, clothing and other protective means are involved, the task of this prediction is difficult. Experimental exposures are the rarer the harsher the conditions are; accident or safe survival reports usually lack critical data such as ventilation, wall temperature, and initial body conditions. The exposure of millions of people to air-raid fires during the war has never been investigated thoroughly with respect to heat transfer, survival times, and medical effects.

Figure 1 should be judged with these limitations in mind. It describes safe exposure times for any given environmental temperature. The following assumptions are made: Wall and air temperatures are equal; the convective heat-transfer coefficient is that of free convection for the given temperature difference between air and skin which is initially at 35° C; water condensation on the skin is excluded; air humidity is indicated in the graph. Data refer to a man clothed with 1 cm of normal cloth, or nude; in extreme conditions the "nude" curve corresponds to exposure times of unprotected skin areas. A large number of tests and publications went into Figure 1.

Radiant heat from sources cooler than about 1500° C is nearly completely (in fact, to 97 per cent) absorbed by human skin. The penetration of these radiations through skin and nearly all clothing material is negligible; the only exception known is polyethylene which is fairly transparent up to 20 μ wave length. Metals are excellent reflectors in these spectral regions. Aluminized clothes were mass-introduced by the author during the war as a protection against radiant heat from large fires. They are now a standard item of the fire fighters. White surfaces are better reflectors than metals for radiator temperatures above 2000° C; for example, for sun or for A or H bomb radiation. Of all kinds of heat transfer to man, radiant heat is the easiest to control.

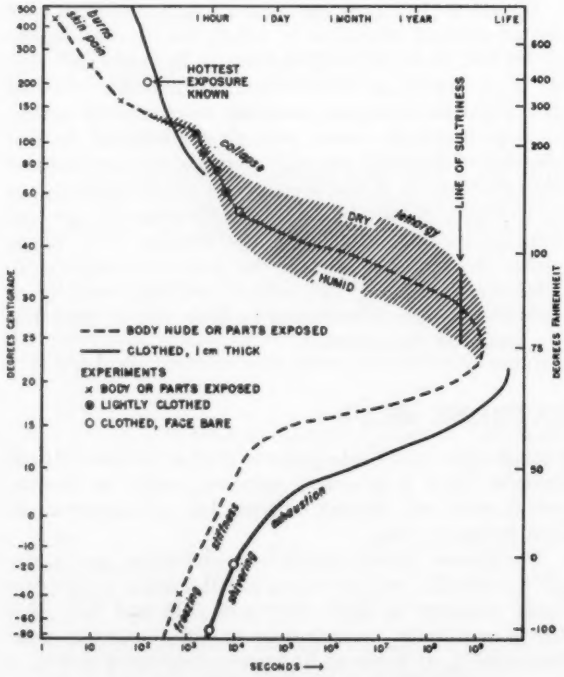


Figure 1. Safe exposure time for a normal man at rest, and nude or covered with 1 cm of normal clothing. Exposures to the left of the curves are generally safe.

With the exception of visible and near infrared light, radiant heat attacks primarily the same part of the body as all other heat flows; namely, the very surface. We therefore lack a radiation sense and have only temperature senses of different kinds. Most safe exposure time, pain, burn, and similar tests on man are made using radiant heat.

Of the many kinds of actual exposures in the burn-heat area, three are outstanding and subject to mathematical treatment of the ensuing skin temperatures, the step function of heat supply, the contact with a hot body of large capacity and conductivity, and the contact heating through a protective cloth.

With nonpenetrating radiant heat, the test person feels consecutively warm, hot, and unbearably painful. This latter sensation proved reproducible, and even the depth of the sensation could be localized. The senses report unbearable pain when a layer of 0.1 mm below the surface exceeds 44.8° C.

If this point is exceeded the pain increases sharply, then declines and later disappears. This always indicates a complete burn of the respective skin area. These latter experiments were restricted to small areas of the author's forearm.

For given conditions, such as people at rest in a normal room radiated on the forearm, the prepain time depends in a simple way on the heat supply. The pain point cannot be reached for heat flows below 1200 kcal/sq m/hr because an increase for peripheral blood flow stops, in time, the anticipated further temperature rise.

The ultimate fate of exposed skin is the burn. Burns are actually based on a chemical-rate process; viz., the protein denaturation. Denaturation of deeper layers is probably more detrimental than that of outer layers. Deeper layers usually receive their heat delayed by a conduction process, and even with the penetrating radiant heat from A-bombs the true overheating of the vital skin layers is delayed. Immediate cooling of the afflicted layers with any means, e.g., with the unheated hands, can cause an impending burn to be subcritical. The process of skin denaturation belongs to the most temperature-sensitive rate processes known. Therefore the smallest possible cooling might help.

Naked skin, exposed to less than 1200 Kcal/sq m/hr heat supply or to a calm room of less than 2000° C air temperature, generally can defend itself. We are entering, then, the realm of collapse heat. Times are now so long that precooling plays a minor role, sweating and peripheral circulation a decisive one. The main limiting factors are body temperature and circulation, practically measured by the heart rate. These increases are shown in Figure 2. The abscissa is the true time of exposure divided by the tolerance or safe exposure time. The human performance as indicated by Link-trainer errors is near normal for the first three quarters of the exposure. During the last quarter, dizziness, faintness, tingling and numbness of the skin, mental confusion, anxiety, blurred vision, and nausea quickly increase until sometimes later a rather startling breakdown occurs. These data are based, mainly, on U.C.L.A. experiments.

IV—REACTION TO EXTREME COLD

Experiments on physiological responses of the human being to whole-body and local-area cooling (the hand only) have ranged from studies of survival rates of men exposed in ice water, to relatively minor cooling in reduced air temperatures. This investigation is concerned with the individual's ability to perform in cold environment.

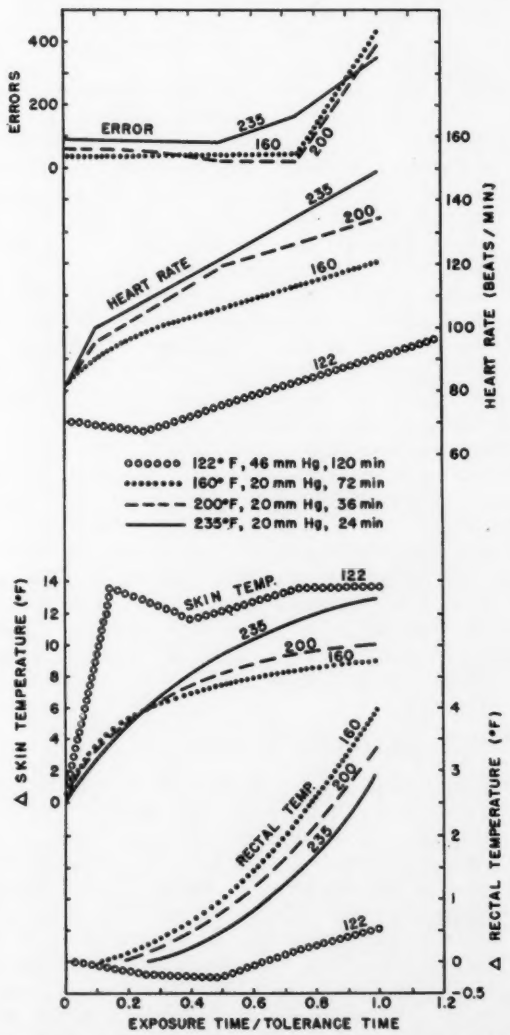


Figure 2. Physiological body changes and Link-trainer errors in man exposed to warm environments. At value 1.0, the experiment had to stop due to impending breakdown.

Of the two types of generally accepted temperature receptors, i.e., peripheral and central, the physiological responses to cold environment are most probably initiated via the peripheral thermal receptors in the skin. The interaction of these peripheral receptors and the central receptors is complex and poorly understood. It is clear, however, that the physiologic adjustments to temperature are mediated through the hypothalamus.

Immediately on being exposed to cold, there is a general peripheral vasoconstriction manifested by an immediate drop in all of the skin temperatures. The most distal parts of the extremities cool the farthest and the most rapidly while the trunk cools more slowly. The face cools the least of all of the body surfaces. The vasoconstriction that takes place in an experiment of this type is a general autonomic response on the part of the body. The surface temperatures fall not only because the room temperature is lowering, but also because the blood supply to the surface has been reduced (the blood moving inward to protect the vital organs). The peripheral vasoconstriction seen in whole body cooling involves not only the arterial system but also the venous system. This results in a shift in the distribution of blood within the body such that the volume of blood contained in the central organs increases during acute cold exposure.

In addition to the cardiovascular adjustments just described, there is also a change in the metabolic heat production of individuals exposed acutely to cold. The increase in metabolic heat production is, for practical purposes, entirely due to shivering. If a person were not confined by the experimental procedure, the shivering could just as well be replaced by voluntary muscular activity.

The application of cold to the hand causes cardiovascular adjustments in the whole body. When the hand is immersed in ice water or exposed to cold in an air box, there is a general whole-body vasoconstriction. This vasoconstrictor response to local cooling is a variable matter occurring to greater degrees in some people and to lesser degrees in other people. Such a response to hand cooling is part of the basis for the development of the so-called cold-

pressor test primarily designed to select those people with hyper-reactive vasomotor systems. In the cold-pressor test, the extent of the vasoconstriction is measured by an increase in the systemic arterial pressure. Further, if one conducts the hand cooling experiment and at the same time arranges to record blood flow on the fingers of the opposite hand, he will note that there is a decrease in the finger blood flow in the contralateral hand when the test hand is immersed in the ice bath.

ACCLIMATIZATION EXPERIMENTS

The acclimatization experiments take the form of carefully studying a group of subjects under controlled conditions and then restudying the same group of subjects after they have been caused to live in a cold environment, either under actual field conditions or in laboratory cold rooms for a variable period of time. The observations may be summarized generally by saying that the individual who was acclimatized kept his extremities warmer at the expense of permitting the temperatures of the trunk to become colder when exposed to a standardized whole-body cooling experiment.

To date, physiologic studies have failed to reveal any parameter that can be assigned the role of the basic determinant of individual differences in response to cold. Short-term acclimatization studies offer meager evidence of adaptive physiologic changes. Although the response of an individual to various cold-exposure tests can be altered by subjecting that person to prolonged cold exposures over a number of days, there is no common physiological parameter to which this change in response can be attributed.

It is possible that the acclimatization we see may be on the basis of changes in the subject's cortical interpretation of the cold stimulus with subsequent modification of the autonomic responses elicited by the stimulus. The average resident of the more temperate climates is relatively inexperienced with regard to exposure to severe cold. Such exposures are new and can evoke a profound autonomic reaction on the part of the individual. Familiarity with the stimulus along with learning that he has the ability to get along in cold may change the individual's initial response to sudden cold exposure.

For example, consider the subjective response of the Eskimo to the hand-cooling experiments previously described. As anyone who has done this experiment will know, immersion of the hand in ice water for a period of 30 min is, indeed, a painful experience. The majority of Caucasian subjects will complain, some quite bitterly, of the pain experience during the test. In conducting the study on Eskimos, however, a fair number of them would fall asleep for the duration of the experiment while their hands were immersed in the ice water. It would be difficult to argue that the Eskimo wasn't receiving the same peripheral stimulus as was the white subject. In studies of pain thresholds of these same natives, it was found that they were not different from Caucasian subjects.

An altered emotional state may entirely change the response of a subject to cold exposure. Hand-cooling experiments were being conducted in the laboratory on a small group of subjects, and repeated observations had been made on one subject in particular. On one occasion he came into the laboratory after having completed an examination over which he was quite disturbed. He stated that he was in a state of tension and even after the usual equilibration period before starting the experiment, he was still quite agitated. On three previous runs, this subject had given essentially normal response. On the day in question. however, he failed to exhibit any rewarming at all, and the hand cooled to bath temperature and stayed there for the full half hour. During the experiment he complained bitterly of pain in the cooled hand. The hand remained painful for several hours after the experiment and as a result of this experience, the subject refused to participate in further studies. This is a good example of how emotional state can modify the response of the individual. It is apparent that the subject just mentioned would have been considerably handicapped had he been required to perform manual tasks in a cold environment in his emotional state at the time of his last experiment.

V—EXPOSURE TO INFRARED RADIATION

Recent studies of the changes in skin temperature occurring during exposure to thermal radiation have permitted estimations of the "thermal inertia" of the skin and of the measurement of the temperature end point for threshold cutaneous pain. The methods employed in these investigations required blackening of the skin surface and exposure to relatively intense radiation. Under these conditions, vasomotor and other responses of the skin are found to cause a variability in the skin's thermal inertia; in addition, there may be some influence of the blackening material upon the heating of the skin. It was therefore proposed to study the small temperature changes occurring when the skin is exposed to long-wave, nonpenetrating infrared radiation.

The present problem required the solution of the heat-flow equation under the following assumptions: The skin is considered as the surface of a thermally homogeneous layer through which there is initially a constant heat flow from the core of the body to the skin surface and thence into the environment through a surface layer of air. The heated area is assumed to be so large that there is no lateral heat flow in the area under consideration but flow only down the linear gradient perpendicular to the skin surface. The core temperature is assumed to be held

constant by the flow of blood, and the skin temperature to have an initial value which is higher than the ambient temperature. The blood flow and the heat production per unit volume in the outer layer are assumed to be small. Thus there is thermal equilibrium initially with the same quantity of heat flowing into and out of the gradient layer.

(The authors develop heat-flow equations to determine the temperatures at any depth in the layer as a function of the time after the start of irradiation).

It is doubtful whether completely accurate boundary conditions can be stated for the problem involving heat flow into the living skin, or whether, even if actual boundary conditions could be stated, an exact mathematical solution would be forthcoming. It must be recognized that the skin is not a metabolically inert, thermally homogenous solid with a linear thermal gradient across it in which there is no lateral flow of heat.

METHOD

The apparatus used for irradiating and measuring the temperature of test surface simultaneously is shown diagrammatically in Figure 3. All of the components were rigidly mounted on a heavy stone-topped table. A circular electric hot plate having a diameter of about 12 cm served as the heat source. The heater was thermally shielded and positioned so that its maximum radiation was directed toward the test surface. The heater temperature was monitored with a copper-constantan thermocouple and during experiments was maintained at about 250° C. A vertically sliding heater shutter separated the heat source from the test surface. The position of the heater shutter was continuously adjustable and could be manipulated to determine both the extent and duration of test-surface heating and subsequent cooling. An asbestos face shield containing a circular aperture of about 37 cm^2 was used to position the test surface during the experimental procedure and also the blackened cone of a Leslie cube, which was used for calibration purposes. Measurements of the distribution and intensity of radiation in the area enclosed by the face-shield aperture showed that local intensities measured in the periphery of each quadrant and in the center of the aperture differed by less than 3 per cent from the average intensity. The magnitude of applied radiation was between 2 and 3 $mcal/sec/cm^2$ and was measured in all four quadrants of the aperture at the beginning and end of each observation. About an hour was required for the radiation source to warm up and reach equilibrium.

Seated subjects were positioned so that a central area of the unblackened forehead was exposed through the face-shield aperture. Care was exercised to insure that only nonsweating subjects in thermal equilibrium with normal room temperatures (20-25° C) were used. The unblackened surface of a

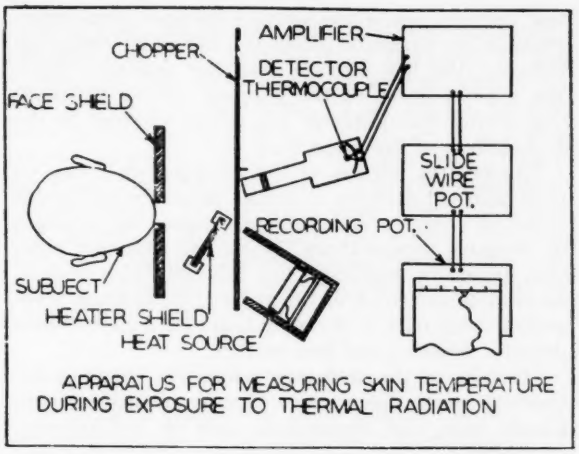


Figure 3. Schematic diagram of the apparatus used for irradiating a test surface and simultaneously measuring its temperature. The heat source was a circular electric hot plate, its temperature maintained at 250° C. The face shield was of asbestos.

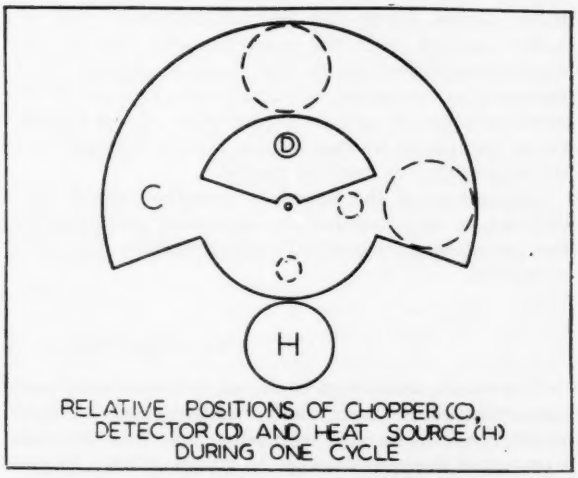


Figure 4. Diagram of the double chopper, showing relative positions of the chopper (C), detector (D), and heat source (H) during one cycle (solid circles exposed; dashed circles occluded). Heater and detector are never exposed at the same time.

block of masonite approximately 0.6-cm thick also was used as a test surface.

An especially designed metal chopper revolving about 12 times per sec interrupted both the radiation emitted by the heat source and that emitted by the test surface. The chopper was constructed of sheet aluminum, cut to the shape shown in Figure 4, and concentrically balanced around the axle on which it was mounted. Circular areas representing the heat source and detector-tube opening are shown projected onto the chopper at selected instants during one chopper revolution in Figure 4. The peripheral area of the chopper interrupts the radiation exchange between the heat source and the

test surface, while the central chopper area interrupts in an opposite phase the radiation exchange between the test surface, and the detector. Thus, the cut-out areas of the chopper are so arranged that heater and detector are never exposed to the test surface at the same time.

The central portion of the chopper was covered with polished silver to minimize radiation exchanges between chopper and detector caused by changes in chopper temperature. When the chopper itself was heated by holding a hot soldering iron near it, no change occurred in the record. Deflections were proportional only to the radiation exchange between detector element and test surface.

(Results of the tests are tabulated, showing the thermal inertia for surface heating of unblackened human skin, and comparison tests on unblackened masonite).

RESULTS

Typical heating curves for the test surfaces studied here, namely, unblackened masonite and human skin, are shown in Figure 5. Examination of these curves shows the reproducibility of the results obtained with the apparatus, as well as the qualitative difference in the thermal properties of masonite as compared to human skin. The relatively rapid increase in surface temperature of the masonite as compared to that of the skin is indicative of its relatively low thermal inertia.

Limitations of the heat-flow equations make predictions of skin heating an empirical phenomenon that must be investigated experimentally for each condition.

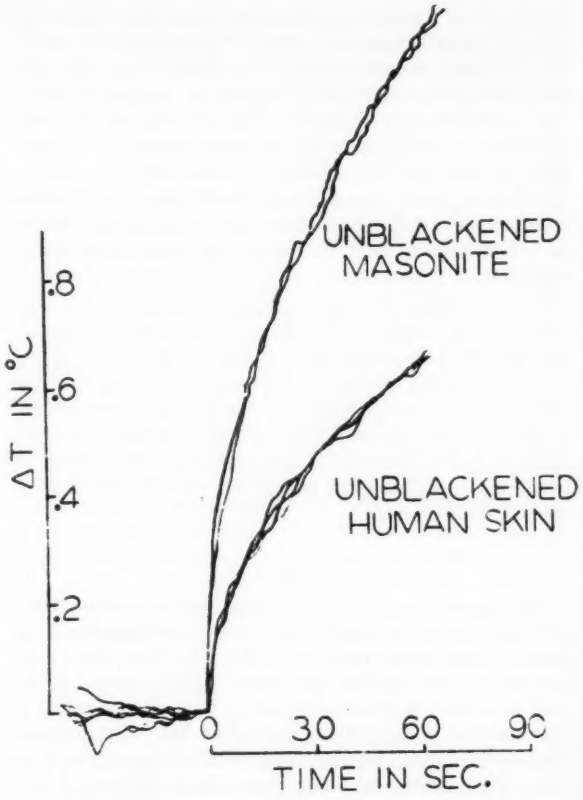


Figure 5. Recordings of six heating curves of the skin, and two of masonite, with exposures to 2.65 mcal/sec/sq cm radiation intensity.

VI—HISTOLIC STUDIES OF BURNS

The atomic bombings of Japan demonstrated how important it is, from both military and medical standpoints, to be able to predict heat flow through tissue and thermal damage to tissue. About 90 per cent of the Japanese who sought medical aid within the first week after the bombings did so because of thermal burns, and in Hiroshima alone there were 70,000 such casualties.

"PUNISHMENT INTEGRAL"

Predictions of the severity of injuries which might be sustained by one's own troops or of those which would be inflicted on the enemy are dependent on knowledge of the response of skin to exposure to various quantities of thermal energy. About 10 years ago, Henriques and Moritz determined the histologic effects of low-temperature, long-exposure, contact burns. Their "punishment integral" has subsequently been used to predict the depth of damage from a given energy input, the median effective exposure for various levels of damage, and the differences to be expected from various input pulse forms.

The use of the punishment integral requires one to assume that a given quantity of energy will always be more destructive if it is delivered during a short exposure time than if delivered over a longer period of time. The same quantity of energy will result in a higher temperature with the shorter exposure. Thus the skin is treated as a passive receiver. There is no provision for the possibility that the skin might react differently to different temperatures and that the type of reaction might influence the severity of the burn.

This paper, based on the histologic demonstration of radiant-thermal-energy damage to tissue, points out some of the reasons why any damage equation which treats the skin as a uniform passive receiver must have a very limited application.

EXPERIMENTAL METHOD

The experimental animals were young Chester White pigs anesthetized with intraperitoneal Dial with urethane (Ciba) in doses of 70 mg per Kg of body weight. These animals have skin very like that of humans. The hair was removed with electric clippers and the skin was gently washed. The heat

source was a modified 24-in. army carbon-arc searchlight which permits accurate control of the radiant exposure and exposure time.

Eighteen to 24 hr after the burns were placed, biopsies were taken across the injured areas so that normal tissue was included on each side of the burn. The biopsies were fixed in 10 per cent formalin, embedded in paraffin, and stained by a method which has been described for the differential staining of burned and normal tissues. The depth of damage was measured with the aid of a ruled ocular in the microscope, and a comparison was made between the percentage of thickness of the skin burned and unharmed.

RESULTS OF TESTS

The results from microscopic assessment of the 5-cal-per-sq-cm burns show that, at this exposure level and within the times investigated (0.5 sec to 30.0 sec), the severity of the injury decreases as exposure time increases. This finding merely confirms in another manner an earlier observation that increasing the exposure time necessitates an increase in the total energy input in order to produce burns of equal severity.

In the case of the 16-cal-per-sq-cm burns, contrary to the 5-cal-per-sq-cm burns, the most severe injury does not occur with the shortest exposure time. The extent of damage is essentially the same with the 0.5 and 30.0-sec exposures, but the energy has been more destructive with the 5.0 and 10.0-sec exposures.

At 10 cal per sq cm, radiant exposure, with a square pulse, does more damage if delivered in 3.0 sec than it does if the exposure time is either 0.3 or 10.0 sec. The simulated atomic-bomb pulse perhaps causes less damage during the 12.65-sec exposure than it does with the two shorter times, both of which result in similar injuries. However, there is no marked difference due to variation in either pulse shape or exposure time.

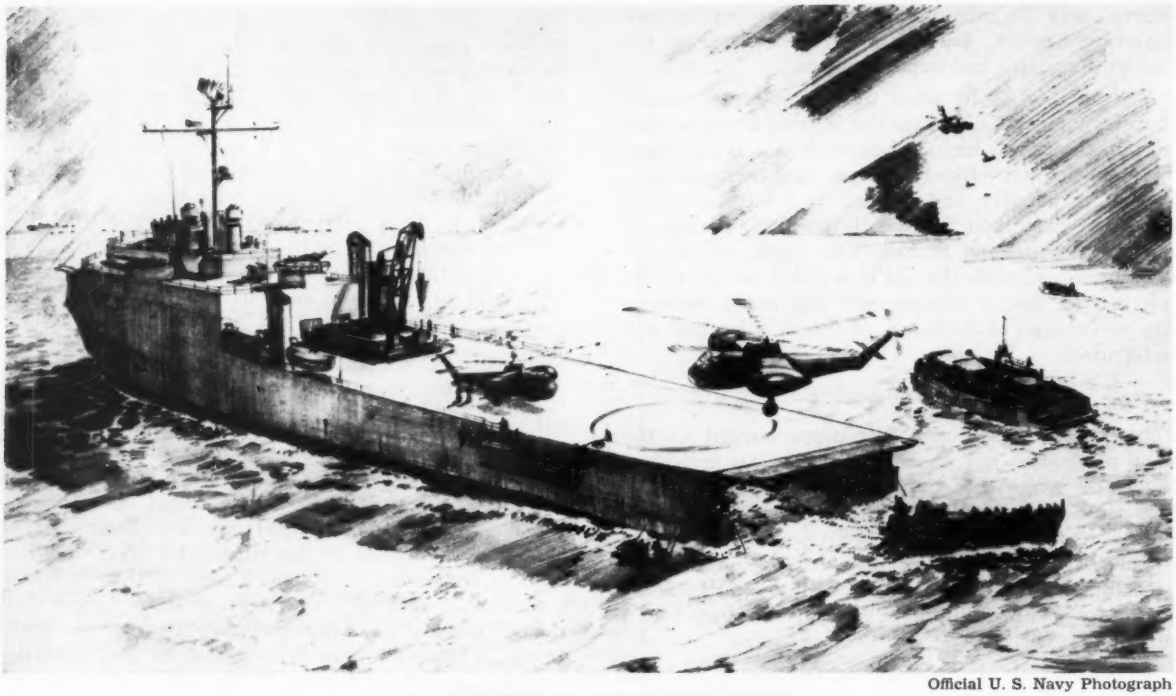
The effect of a given quantity of radiant thermal energy depends on the exposure time, but the most effective exposure time for one dose is not necessarily the most effective for another. Within the time limits investigated, 5 cal per sq cm do the most damage during the shortest exposure time.

A damage-prediction formula which assumes that a quantity of energy is always more destructive with a shorter exposure time might be applicable to mild burns. When, however, higher irradiances are used to produce more severe burns, the factor of exposure time works differently. Under these conditions, a given radiant exposure does not necessarily produce maximum damage when delivered in the shortest possible time. When the energy input is in the form of a square pulse, 10 cal per sq cm are more destructive if delivered in 3.0 sec than if delivered in either 0.3 or 10.0 sec. Similarily, 16 cal per sq cm are more destructive with exposure times of both 5.0 and 10.0 sec than with times of 0.5, 1.0, and 3.0 sec. It is particularly noteworthy that the 10.0-sec exposure is more destructive than the 3.0-sec one with 16 cal per sq cm, but the reverse is true with 10 cal per sq cm.

THE STEAM BLEB

A probable reason for these differences may be inferred from gross and microscopic examinations of the burns. The 16-cal-per-sq-cm exposure will illustrate this. When this quantity of energy is delivered to the skin in 0.5 sec, a steam bleb is produced. The steam bleb represents a violent surface reaction; the water in the superficial layers of the skin is converted to steam. There is, thus, an abstraction of heat, or a diversion of energy from the deeper tissues. The microscopic appearance of these burns is that of severe dehydration of, and damage to, the superficial layers. If the same quantity of energy is delivered with an exposure time of 10.0 sec, a steam bleb does not form. Temperatures high enough to convert tissue fluid into steam do not obtain, and there is no similar abstraction of energy. A deeper burn which does not show severe dehydration and compression of the superficial tissues results from this exposure.

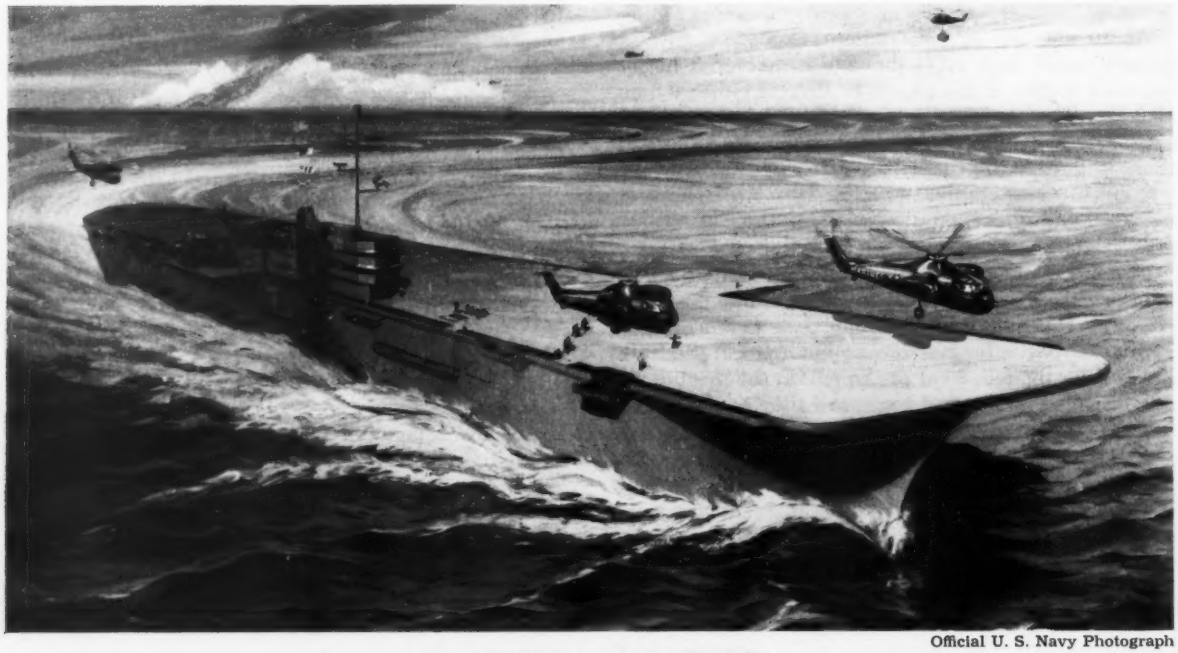
Steam-bleb formation is only one reason why damage-prediction equations which treat the skin as a uniform, passive receiver cannot be widely applicable. Of particular importance from the medical standpoint is the fact that damage to the epithelium of the hair follicles is always deeper than is damage to the dermis. Analysis of the microscopic appearance of the burns indicates that radiant energy penetrates more deeply via the hair shafts than it does through the dermal collagen. It is also possible that temperatures not great enough to destroy dermal collagen will, nevertheless, lead to irreversible damage of the epithelial cells. Whether or not a large area burn can heal without a skin graft is primarily dependent on how many deeply located epithelial cells survive the thermal insult. From the practical point of view of being able to predict the extent of injury, the depth of injury to the hair follicles is more meaningful than is the degree of damage to the other tissues of the dermis.



Official U. S. Navy Photograph

LPD—AMPHIBIOUS TRANSPORT, DOCK

This design combines the functions of an attack transport and an attack cargo ship. The first of its type, the ship can operate landing craft through the stern opening from the well deck. The deck over the stern well provides a helicopter platform, from which helicopters can also transport troops ashore.



Official U. S. Navy Photograph

LPH—AMPHIBIOUS ASSAULT SHIP

This ship is designed to embark, transport and land troops and their equipment by means of helicopters. The ship in the 1959 program will be the second new ship of its type. The abil ty of the ship to land an assault force without being limited to favorable beach terrain is its most significant operational fe ture.

LIEUTENANT JOHN E. WESLER, U.S.C.G.

A METHOD FOR DETERMINING THE AVERAGE AUDIBLE RANGE OF A SOUND SIGNAL

THE AUTHOR

is a graduate of the United States Coast Guard Academy, receiving his Bachelor of Science degree and commission in the Coast Guard in 1949. After serving two years in the USCGC MENDOTA, he entered M.I.T. and earned a Master of Science degree in 1952, majoring in Acoustics. He then earned a Master of Science degree in Optics in 1954 at the University of Rochester. He is presently assigned to the Civil Engineering Division, Office of Engineering, Coast Guard Headquarters, Washington, D. C., working in the field of aids to marine navigation.

A RECENT PAPER in the Journal of the American Society of Naval Engineers[1] discussed in practical terms some of the factors which affect the propagation of sound through the atmosphere over the surface of the sea. In that article, the author described the natural phenomena which limit the audible range of sound signals. Briefly, these factors include the intensity and frequency of the sound, meteorological conditions of humidity, wind and temperature, spherical divergence, and the aural threshold of the observer. It is the purpose of the present paper to outline a practical method whereby these factors may be used to establish a meaningful measure of the performance of any given sound signal, in terms of the average audible range of that signal. In this manner, a tool will be available to permit comparative rating of different signals, to permit the specification of definite design criteria for new signals, and to aid in the regulation and specification of sound signal performance for new installations.

BACKGROUND

What is the average audible range of a sound signal, anyway? This is a question often asked about a ship's whistle or a fog signal. Quite naturally, this range is the average distance to which the sound emitted by a signal can be heard by the average listener. But how can this value be measured, and equally important, how can it be specified for a new installation?

One obvious method of measurement is to operate the signal and have several observers proceed away from it until each can no longer hear the emitted sound. If a large number of such observations with different observers can be made, and the results averaged, a good value of average audible range of that signal in that particular location can be obtained. This method is quite acceptable, and in fact has been used in the past in evaluating different types of fog signals.

But this method is cumbersome and time consuming, even under the best conditions. The spread

of the individual observations is large. For example, a signal may be heard loud and clear at three miles on one afternoon, and be completely inaudible to within one-half mile on the following morning. Further, there is no guarantee that the same sound signal will produce the same result in another location. And most important, this method is unsuitable for use where design criteria or regulations for audible warning devices must be specified. It requires that the proposed installation or equipment be set up in the desired location and actually operated. This procedure involves considerable time and expense. If the design criteria or regulatory requirements are not then satisfied, this time and expense has been wasted. Manufacturers and designers are hesitant to proceed under such indefinite conditions, to say the least. And without definite criteria as to the operational performance of a proposed sound signal, new equipment must be purchased on faith alone, or at best a good guess.

In an effort to overcome these difficulties, the author has explored possible methods of determining in a practical manner the probable performance of any given sound signal, without the necessity for exhaustive field tests. Although derived for the specific case of fog signals used in aids to navigation, the results are equally applicable to any type of sound signal, including ship's whistles, since the important period of operation of such equipment is normally during times of reduced visibility due to fog. The following discussion is intended to mention briefly some of the factors which required consideration, and to present what the author considers a practical solution to the problem.

FACTORS INVOLVED

As mentioned at the beginning of this paper, the audible range of a sound signal depends primarily on the intensity and frequency of the sound, the attenuation of the medium through which it travels, and the minimum loudness to which the receiver will respond. The dependency of these factors is similar to that involved in the propagation of light, or of radio waves. Only the names of the units have been changed—possibly to protect the acoustical engineer.

Intensity

The intensity of a sound is expressed in logarithmic units called decibels. Usually the first mention of this unit creates an urge in the average reader to seek more interesting reading elsewhere. But the use of a logarithmic unit such as this is necessary, because of the vast range of sounds which must be represented. Consider the difference between the rustle of leaves on a quiet night, and the roar of a nearby jet aircraft engine. The jet's noise may be on the order of 1,000,000,000,000 times as intense as that of the poor little leaf. The use of a linear unit encompassing this wide range of values quickly becomes impractical, and the use of logarithms is wiser. The decibel is defined as ten times the log (to the base ten) of the ratio of the sound's intensity to a reference intensity value. In symbols, the relationship may be expressed as:

$$N = 10 \log_{10} I / I_{ref} \text{ decibels.} \quad (1)$$

Since sound intensity is proportional to the square of the pressure associated with the traveling sound wave, the intensity level is often written as:

$$N = 20 \log_{10} p / p_{ref} \text{ decibels} \quad (2)$$

and is referred to as the sound pressure level. The reference value of intensity (I_{ref}) is 10^{-16} watt/cm^2; the reference value of sound pressure (p_{ref}) is 2×10^{-4} dynes/cm^2. The reference values are based roughly on the absolute minimum sound to which the human ear will respond under ideal conditions.

Frequency

The frequency of a sound is expressed in cycles per second, in the same manner as alternating electrical current or radio waves. Audible sounds range in frequency from about 15 cps to about 15,000 cps.

Sound pressure level may be measured through the use of a sound level meter, often called a DB meter. Frequency may be measured through the use of a frequency-analyzing instrument, normally designed as an attachment to the sound level meter for convenience.

ATTENUATION FACTORS

So far, so good. What if we can measure the intensity and frequency of a sound signal—can we use this information to determine its performance at a distance? Sound waves, traveling through the earth's atmosphere, are decreased in intensity by a number of factors. For the present, the following factors will be discussed: (1) spherical divergence; (2) absorption and scattering by air molecules and suspended particles in the air; (3) ground absorption; and (4) refraction by wind and temperature gradients. As Mr. Saltus pointed out in his paper[1], other factors also enter into play, but the above are the most important.

Spherical divergence

Spherical divergence may be visualized as the surface of an expanding sphere, growing larger and larger as the sphere enlarges. The energy which originated at the center of the sphere is spread thinner and thinner as the sphere expands, so that the intensity or energy per unit area decreases inversely as the square of the distance from the center of the sphere—the old inverse square law. This decrease in sound intensity is always present in normal sound propagation, and may be calculated by the following relation:

$$\text{decibel decrease} = 20 \log_{10} R / R_{ref} \text{ decibels.} \quad (3)$$

Average attenuation

The remaining factors affecting the intensity of a sound wave traveling through the atmosphere—scattering and absorption, ground absorption, and

refraction—can seldom be separated and individually measured. Theoretical studies have been made into each effect, and some experimental data taken under controlled conditions are available. Most information available, however, lumps the several factors into one attenuation factor with no attempt at classification. In 1933, a series of experiments was reported[2] to measure the attenuation of sound traveling over water in fog. Although obtained some years ago, these data constitute the most reliable information available describing the performance of a sound signal under these specific conditions. Figure 1 shows the average attenuation of the atmosphere for sound propagated over water through average fog conditions. This curve does not include the effect of spherical divergence, which must be calculated separately by relation (3) above, and added. Figure 1 provides the attenuation in terms of decibels decrease per nautical mile of travel. Recalling that decibels are actually ratios of sound intensity or sound pressure, this figure is a measure of the percentage of sound lost in traveling through one nautical mile of average fog over water. The decibel decrease for any other distance is the direct product of the value per mile times the distance in nautical miles.

It must be pointed out that the data of Figure 1 are average data only, taken on a statistical basis. Attenuation may vary widely at any given time, due to the weather conditions actually present. Thus, these data cannot be considered as the absolute attenuation at any specific time, but only as the average values to be expected over long periods of fog.

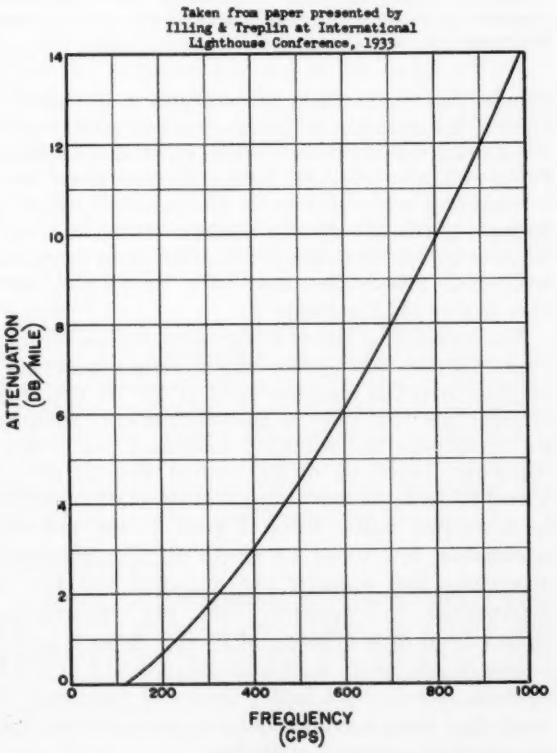


Figure 1. Average Acoustical Attenuation of the Atmosphere

Aural threshold

The average listener judges his ability to hear a sound on the apparent loudness of that sound. Thus, a crash of thunder is "very loud"; the voice of a person speaking at a distance is "soft." This sensation of loudness is chiefly a function of sound intensity, but it is also dependent on frequency. In order to correlate the psychophysical sensation of loudness with measurable values of sound level and frequency, extensive tests have been conducted under laboratory conditions by a number of workers. Many observers have been asked to listen to different sounds, and to indicate which had the same apparent loudness. Figure 2 is the accepted data on equal loudness contours[3], originally reported by Messrs. Fletcher and Munson in 1933[4], and generally known as the Fletcher-Munson curves. Each of this family of curves indicates the values of sound level necessary at various frequencies to produce the same apparent loudness sensation to the average listener. Thus, for example, a 100-cycle note of 61 db produces the same sensation of loudness as a 1000-cycle note of 40 db. The unit of loudness level is the phon—they had to call it something! By definition, the loudness level in phons of a sound is numerically equal to the intensity level in decibels of a 1000-cycle note which is apparently equally loud to the average listener. Thus, our 61 db, 100-cycle note mentioned above has a loudness level of 40 phons. The zero phon loudness level is approximately the absolute minimum to which the average human ear will respond. A sound with a loudness level of 120 phons

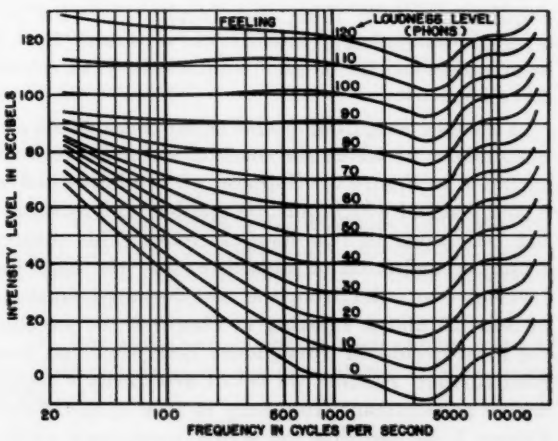


Figure 2. Equal Loudness Contours

or more will probably produce a sensation of feeling and often of pain in the normal ear.

Returning specifically to the problem of the detection of a fog signal aboard ship, it is logical that the fog signal must have a certain loudness to enable it to be heard above the ambient noise already present on the ship at the position of the listener. The 55-phon loudness level has been established as the limiting level required for audibility on the bridge of the average ship. That is, any sound which has a loudness level of 55 phons or more will be identified by the average listener on the average ship's bridge. Any sound which has a loudness level less than 55 phons will be inaudible, and therefore useless to the average observer.

THE PROPOSED METHOD

With the foregoing information as a background, a method of determining the average audible range of a sound signal under the assumed conditions can be developed. If the intensity and frequency of a sound signal can be measured, and the spherical divergence and attenuation applied, the range at which the loudness level of the sound falls to 55 phons can be computed for average conditions. This may then be defined as the average audible range of the sound signal in question. Conversely, and more important from a design or regulation viewpoint, the problem may be worked backwards. For any desired average audible range, the intensity level necessary for a sound signal to meet that requirement may be computed and specified. A single measurement of intensity level and frequency under proper conditions will then show whether or not a new signal will comply with the required performance criterion. This latter approach has been used to develop Figure 3. This family of curves shows the sound intensity levels which must be generated at 25 feet and at various predominant frequencies in order to be audible under average fog conditions to various ranges. In computing these requirements, the Illing and Treplin[2] data for the average atmospheric attenuation of sound in fog over water, and the 55-phon loudness level threshold have been used.

A sample computation will serve to show the exact manner in which the various factors have been included in Figure 3. Suppose we are interested in a sound signal which must be audible under average fog conditions to two nautical miles. This means, from our definition of audibility, that the loudness level at two miles from the sound source must be at least 55 phons. Looking at Figure 2, we see that we must decide on a frequency before we can proceed further. Assume we select arbitrarily a signal whose predominant frequency is 1000 cycles. From Figure 2, we see that the sound must have an intensity level of at least 55 db at two miles in order

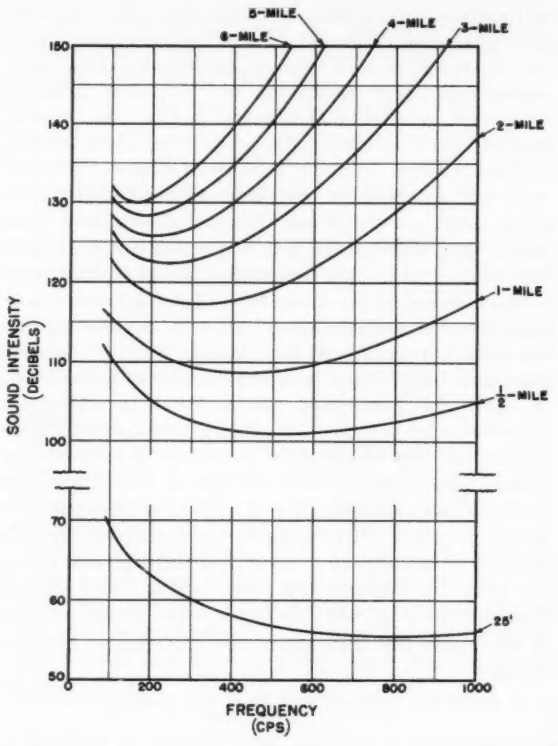


Figure 3. Sound Intensities Measured in Free Field at 25' Required to Produce 55-Phon Loudness Level at Various Distances

to meet this requirement. From Figure 1, the attenuation of the sound in traveling over two miles under average fog conditions is 2 times 14.2 or 28.4 decibels. From equation (3), the spherical divergence loss in traveling from 25 feet to two nautical miles is 20 log (12,152/25) or 53.8 decibels. Thus, at a distance of 25 feet from the source, the sound intensity level of a 1000-cycle signal must be 55 plus 28.4 plus 53.8 or 137.2 decibels.

The choice of a sound signal with a predominant frequency of 1000 cycles was a rather poor one, judging from the intensity level of 137 db required to meet the two-mile range requirement. Suppose we recompute the intensity necessary for a predominant frequency of 300 cycles. For 55 phons, from Figure 2, we must have at least 60 db intensity level at two miles. From Figure 1, the average attenuation is 2 times 1.8 or 3.6 db. The spherical divergence loss remains 53.8 db, since this loss is independent of frequency. Thus, the required intensity level at a distance of 25 feet from a sound source of 300 cycles is 60 plus 3.6 plus 53.8 or 117.4 decibels. Hence, by a better choice of frequency, a much less intense sound source is required to meet the specified range of audibility.

The family of curves of Figure 3 was obtained by

a series of computations similar to those just completed for the various ranges shown.

Conditions of measurement

In order to standardize the method of specifying the intensity level requirements for Figure 3, certain conditions for the measurements of intensity and frequency had to be established. In order to obtain reliable and repeatable data, measurements in a "free field" were specified. This means essentially that only the direct sound from the sound source is to be considered, and all reflected sound waves or echoes from adjacent objects eliminated. The simplest method for obtaining free field conditions is through the use of an anechoic chamber (literally, a room with no echoes). Such chambers are normally found only in well equipped acoustics laboratories, and consist of isolated rooms in which all walls, floors and ceilings are lined with sound absorbing wedges, usually of Fiberglas. Satisfactory measurements may be taken in an open field on windless days, however, if proper correction is made to eliminate the sound wave reflected from the ground and from any nearby obstacles.

A distance of 25 feet was specified as the distance at which measurements are to be made. This distance was chosen as a compromise between the necessity for getting beyond the "near field" of the sound source, and the limitation of size of anechoic chambers presently available in this country. Ordinarily, "far field" conditions will exist at distances greater than three wave lengths, or greater than twice the largest dimension of the sound projector, whichever is greater. For most fog signals in use today, a distance of 25 feet is adequate. Measurements in anechoic chambers have shown that "far field" conditions do exist at lesser distances than this. By "far field" conditions, it is intended to mean that the sound source acts essentially as a point source, and that the expanding wave front is spherical. Under these conditions, the inverse square law is proper.

Measurements at distances other than 25 feet may be used, and corrected to 25 feet by the use of the inverse square law. When such corrections are made, however, it must be shown that far field conditions definitely are present. Measurements in the open at distances greater than 100 feet are not recommended, since meteorological conditions, even on a calm day, can seriously affect the accuracy of the results.

Complex sounds

The foregoing procedure for determining the average audible range of a sound signal, by which Figure 3 was calculated, assumed that the sound under consideration had a predominant frequency. If a sound signal produces a complex sound wave (i.e.: one which is rich in harmonics, or which has two or more component frequencies approximately equal in intensity), the use of Figure 3 is not accurate. All of the various component frequencies making up a complex signal add to the apparent loudness. For example, not only the fundamental note of a diaphone fog signal is heard by the mariner, but also the various harmonics of the signal as well, producing the characteristic harsh sound associated with a diaphone.

In determining the average audible range of a complex sound, each of the frequency components must be treated as a separate sound. By application of the proper corrections for spherical divergence and attenuation, the loudness level of each component at a given range may be determined in the same manner as before. These loudness levels of the various components must then be added to provide the total loudness of the overall sound. The 55-phon criterion is then used as the limiting loudness level for the overall sound, also.

The loudness levels of the various frequency components of a complex sound cannot be added directly, however. Because of the basic definition of loudness level (ie: in terms of decibels or logarithms), the phons must be reduced to linear units before direct addition is proper. This procedure requires the introduction of the unit of loudness (as opposed to loudness *level*) called the sone. The sone provides a linear scale of loudness, so that a sound that is 40 sones in loudness is roughly twice as loud as one which is 20 sones in loudness. It is thus a direct measure of the apparent loudness of a sound, and normally is more meaningful to the layman than the loudness level in phons. Figure 4 shows the relationship between loudness level in phons and loudness in sones. This curve is taken from reference 3, which also contains the relationship in tabular form for more precise computations. More recent work[5] on this relationship indicates that minor revisions may be proper to reference 3 in the near future. The proper method of adding loudness levels, then, is to convert each level to its equivalent loudness in sones, add the loudnesses, and convert the total loudness back to total loudness level in phons.

To compute the average audible range of a sound signal having a complex sound output, the following steps are required:

(1) Measure the intensity level and frequency of each component of the complex sound under consideration.

(2) For each component, determine and apply the proper spherical divergence and attenuation factors for each of three or more convenient distances, chosen arbitrarily.

(3) For each component at each range, convert the intensity level to loudness level in phons, using Figure 2.

(4) For each component at each range, convert the loudness level in phons to loudness in sones.

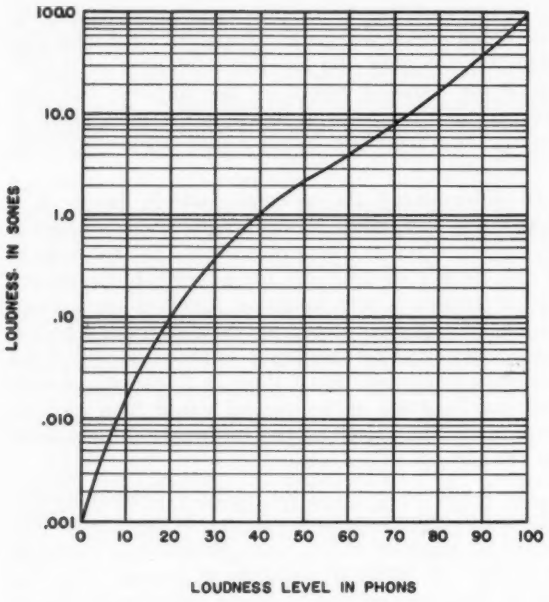


Figure 4. Relation Between Loudness and Loudness Level

(5) At each range, add the loudnesses in sones of the frequency components and convert the total loudnesses to loudness levels in phons.

(6) Plot the values of total loudness level against range.

(7) Pick from the plot the value of range at which the loudness level falls to 55 phons. This value, then, is the average audible range of the sound signal under test.

Ordinarily, frequencies above 1000 cycles need not be included in this computation, since the large values of atmospheric attenuation above this frequency quickly damp them out so that they do not add appreciably to the signal's loudness at significant distances.

Discussion

After reading the explanation of the proposed method for determining sound signal performance given above, it probably appears that the procedure is excessively complicated, and therefore impractical. It must be admitted that the method is not one to be applied by the average mariner in his day-to-day duties. But it is felt that the method outlined does provide a workable tool for the engineer who is involved in the specification, regulation, or manufacture of sound signals. Although seemingly quite complicated when first encountered, the computations required are relatively straightforward and simple. They are very similar to the mathematics involved in Allard's Law in optics, or in radio wave propagation work.

Again, it must be stressed that the results of this method do not provide absolutely reliable range data, dependable at all times. That is, because a laboratory test of a certain signal indicates an audible range of five nautical miles, a mariner cannot be certain of hearing that signal at five miles tomorrow morning. On the average, he should be able to hear that signal at five miles over an extended period of fog, however, assuming the signal is installed and operated properly. On this basis, perhaps it is better to look on the results of this method as comparative ratings of sound signals. Thus, a three-mile signal is better than a two-mile signal.

No matter in what light the results are considered, however, this method does provide useful information on the performance of a sound signal. The results may thus be put to good use in a number of ways—in comparing different signals and different types of signals, in specifying performance levels of new apparatus, in specifying performance levels for purposes of regulation, and in deciding which is the best and most efficient equipment to be used in a given situation. In regard to this last use, the two sample computations used to illustrate the evolution of Figure 3 may be recalled to mind. These indicate clearly that the use of a signal with one predominant frequency may not require as much power as another signal with a different predominant frequency. This is evident from the dips in the curves of

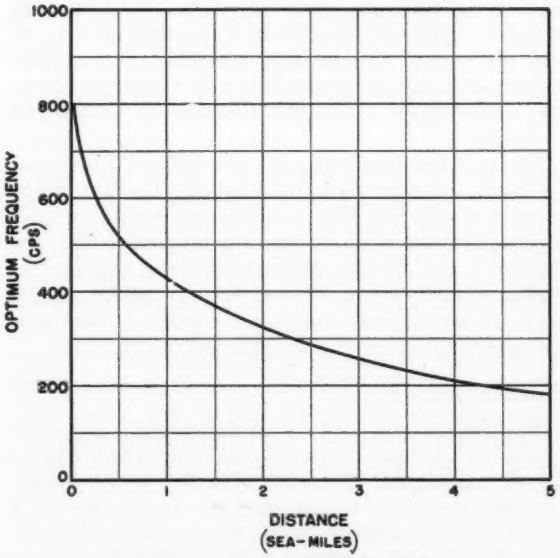


Figure 5. Most Effective Sound Signal Frequency for Audibility to Various Distances, Based on 55-Phon Loudness Level

Figure 3. Figure 5 shows the most efficient frequency for various ranges of audibility—that is, the frequency at which the least intensity is required. Quite often other considerations restrict the choice of frequencies obtainable in a given situation. However, Figure 5 will provide a guide to the proper selection of the best frequency.

The above method of defining the audible range of a sound signal is being used by the United States Coast Guard in its proposed new regulations governing privately maintained aids to navigation. It is felt that all rules governing the use of sound signals must ultimately come to this type of approach to be effective. A word of caution must again be added, however. Because a signal is capable of performing at a certain level in a laboratory test does not guarantee that it will be installed and operated so as to achieve that same level in the field. Laboratory tests can never supplant actual field checks of such signals. But laboratory tests can provide a practical tool for checking the compliance of a new signal with a desired performance level.

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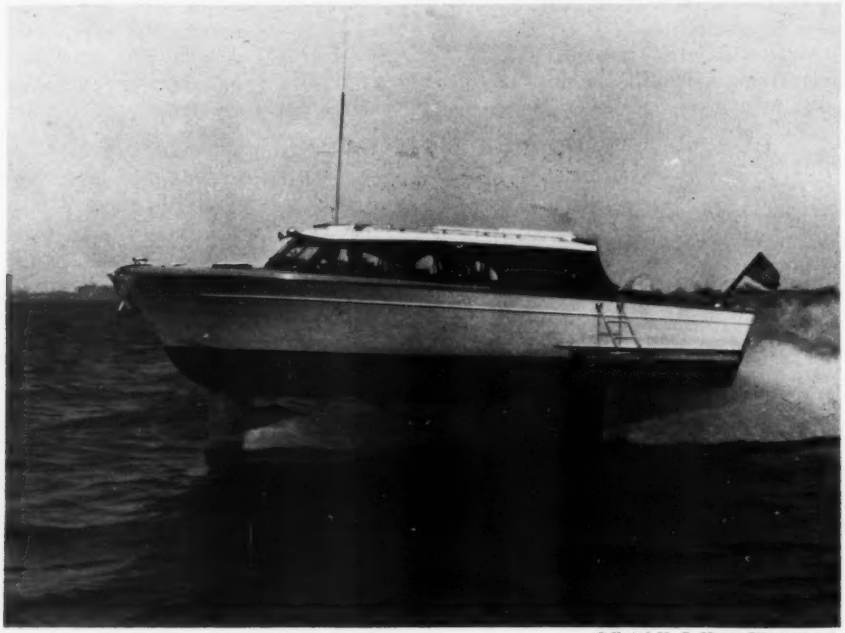
A new type of magnetic memory device has been announced by the Bell Telephone Laboratory. Termed "Twistor," the device is based on the principle that a helical magnetic polarization in nickel wire can be achieved by superposition of a longitudinal magnetic field and a circular magnetic field. The circular field is created by a current pulse through the nickel wire itself. The longitudinal field is created by a current pulse through a copper wire at right angles to the nickel wire. Thus a wire screen woven of the nickel wire and copper wire provides a "bit" storage element at each wire intersection. This simple construction is highly advantageous. Read-out of the stored information is accomplished by over-driving the copper wire in the reverse direction, a signal corresponding to the "bit" appears at the terminals of the nickel wire.

—from "Bell System Technical Journal," November 1957



Official U. S. Navy Photograph

The Office of Naval Research and the Bureau of Ships of the U. S. Navy have been actively engaged in research and development of hydrofoil craft since 1947. This type of craft operates with the hull out of the water supported by the lift developed by hydrofoils (wing-like devices) operating in the water below the hull. A hydrofoil craft will exceed by 50 per cent or more the speed of other types of the same size with the same installed power. It has been demonstrated that a hydrofoil-equipped boat will give better riding qualities in rough water than a conventional boat of comparable size and speed.

Several hydrofoil test craft have been successfully operated using different foil and control systems and have demonstrated the excellent seakeeping quaities of this type boat. It is of interest to note that the hydrofoil principle was used on boats before the start of the twentieth century. Dr. Alexander Graham Bell and Wilbur and Orville Wright were among the early experimenters with foil-supported boats.

There is little doubt that a craft of about 100 tons can be built and operated with the knowledge and hardware available today. The U. S. Navy is examining various possible operational uses for these craft including patrol craft, specialized personnel carriers and landing craft.

One of the test boats developed for the Navy is "SEA LEGS." This 5 ton craft is fitted with two fully submerged foils, one forward and one aft. A high performance autopilot is used to control the position of the boat and foils and has shown outstanding characteristics. The control system includes a height sensing device, integrating gyros, accelerometers, servo-mechanisms and electronic units.

This craft has been evaluated by the contractor, Gibbs & Cox, Incorporated, for several months in the vicinity of New York. The foil and control system show promise of being eminently suitable for hydrofoil supported craft of more than one hundred tons.

COMMANDER W. M. M. FOWDEN, JR., U.S.N. & H. Q. MAR

HULL CRACKS ON DESTROYERS

THE AUTHORS

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H. Q. MAR received B.S.E. degree from the University of Michigan in Ann Arbor, Michigan, in 1926 and M.S. degree, ibid, in 1927. Since that time has been with the Bureau of Construction and Repair, Navy Department; Bethlehem Shipbuilding Corporation, Ltd.; Supervisor of Shipbuilding Office, Quincy; U. S. Naval Dry Dock, Hunters Point; Kiangan Dock and Engineering Works, Shanghai; San Francisco Naval Shipyard; and is presently Design Superintendent, U. S. Naval Ship Repair Facility, Subic Bay, Luzon, Republic of the Philippines.

SUMMARY

This paper reports the occurrence of fatigue cracks in a number of World War II U.S. destroyers and shows some of the causes of these cracks. Although the cracks do not appear to endanger these ships, they are a nuisance and require removing the ships from operation. Since most of these cracks are below waterline, drydocking is usually required. Slight changes in design and construction could eliminate this expensive and bothersome maintenance.

MANY PAPERS have been written in the recent years on failure of ship structures. There is a dearth of report on fatigue failure on ships. This type of failure occurs only after a good many years of operation and it is usually not serious in nature. This has been lost sight of because interest in a ship wanes with its age. The repair of fatigue failure of hull is generally considered a part of the ship's upkeep. When it occurs, an over-simplified explanation of deterioration due to age is advanced and that repair is unavoidable. Any underwater hull repair on a ship requires drydocking. The expenses for drydocking are usually absorbed as part of the routine docking for other work. For a merchantman, the demurrage resulting from the hull repair is looked upon as a part of the annual fixed charges. It is difficult to evaluate from the military point of view, when a naval ship is off the line to effect this type of hull repair. It is the purpose of this paper to confine the discussion to fatigue failures on World War II destroyers and to draw some general conclusions thereon.

It has been generally accepted that failures of welded merchant ships built during World War II period were produced by brittle cleavage fractures and usually propagated at high velocity. Contributing causes of these failures were the deleterious effects of notches, introduced either by design or through method of fabrication of the structures. There was a greater incidence of these failures at

low temperature thus emphasizing the phenomenon of notch sensitivity of steel at lower operating temperature. A great majority of these failures took place during heavy weather at near freezing temperature. Some of the failures occurred in calm sea at a still lower temperature. Some of the vessels fractured while loaded and others were light and in ballast. Case history of failures of these vessels was examined thoroughly by the Secretary of the Navy's Board of Investigation, Acker and Williams and Ellinger (1), (2) and (3), respectively. The average years of service have been relatively low, only a fraction of the expected life of each vessel. Because of this, Jonassen (4) indicated that fatigue has not been an important factor in welded ship failures. In all the above failures, ships with heavy plating such as that of Liberty and Victory cargo vessels and T2 Tankers were the most common ones. There is no record of failure of ships with light plating resulting from brittle cracks.

At the recent International Conference on Fatigue organized by the Institution of Mechanical Engineers, Weck (5) reported that over 80 papers were presented on the different aspects of the fatigue problem. Among those read was a paper given by Russian engineers dealing with fatigue in ships' structures. It was concluded in that paper that in Russia, fatigue is an important consideration in the design of ships. Evidence was cited that fatigue cracks had initiated brittle fractures on some of the Russian ships. In the light of this report, fatigue cracking on ships, which has not heretofore been considered an important factor in welded ship failures deserves further appraisal. An analysis of some of the recent hull cracks on World War II destroyers might be timely in this respect.

The Naval Ship Repair Facility, Subic Bay is one of the many activities engaged in the repair and servicing of naval vessels. In a period of thirty (30) months, thirty (30) destroyers of the DD445, DD692 (Short Hull) and DD710 (Long Hull) classes have been repaired for hull cracks. Some of these destroyers were repaired the second time for subsequently developed cracks. These destroyers, built during 1942-1946 period, Table I, have been operating approximately thirteen years. It is acknowledged that age and general deterioration are the reasons for the hull cracks. While this is not an alarming number of destroyers repaired at Subic over this period, yet the recurrence of the same type of shell repairs indicates that a closer examination of this phenomenon is in order. Repairs on 114 hull cracks have been recorded, most of which occurred in the shell plating around the machinery spaces. Numerous other cracks, such as tank bulkhead plating and stiffeners, webs of flanges of frames, brackets and other internal structural components are not included in the above total. The type and

TABLE I—TABULATION OF AGE OF DESTROYERS REPAIRED AT SUBIC

Destroyer	Class	Commissioned
A	L	'45
B	L	46
C	L	46
D	L	46
E	L	45
F	L	45
G	L	45
H	L	45
I	L	45
J	L	45
K	L	44
L	L	46
M	S	44
N	L	45
O	S	44
P	S	44
Q	S	45
R	S	46
S	L	45
T	L	45
U	S	44
V	S	44
W	S	44
X	L	45
Y	L	45
Z	X	42
AA	X	43
AB	S	44
AC	L	45
AD	L	45

LEGEND: L=710 CL (Long Hull) S=692 CL (Short Hull) X=445 CL

location of cracks on the destroyers are shown by tabulation, Table II.

An examination of fractures indicates the prevalence of fatigue type of failure. Fatigue failures are the results of repetitive reversal of the stress cycles in the region where the stress is highest, the mid-length of a ship. Vibrations and pulsations of machineries augment the primary stress system of the hull and add to its effect. All these dynamic stresses are added to the static stresses of the weight and cargo distribution of the ship itself plus thermal stresses and residual stresses from fabrication. The continued stressing causes a crack to propagate slowly until the remaining cross sectional area of the plating fractures from overload.

To simulate the alternating stress occurring in service, full scale assemblies of plating and stiffeners

TABLE II—TABULATION OF DESTROYER HULL CRACKS REPAIRED AT SUBIC

TYPE OF CRACKS	DD 445 CL (2 VESSELS)			DD 692 CL (SHORT HULL) (9 VESSELS)			DD 710 CL (LONG HULL) (19 VESSELS)			TOTAL CRACKS
	DIV. A	DIV. B	DIV. C	DIV. A	DIV. B	DIV. C	DIV. A	DIV. B	DIV. C	
Shell		2	2	4	3	3	7	33	10	64
Insert or Doubler Plates		2			7			24		33
Along Welds of Plate Butts					1			3		4
Coaming & Baffles of Sea Chest		2			2			8	1	13
TOTAL		6	2	4	13	3	7	68	11	114

DIVISION "A" FWD. OF MACH. COMPT. - (STEM TO FR. 72)
DIVISION "B" MACH. COMPT. - (FR. 72 - FR. 148)
DIVISION "C" ABAFT MACH. COMPT. - (FR. 148 - STERN)

have been made as indicated by Weck (6) to determine the effect on fatigue endurance. The number of cycles is in the order of 10^6. The number of cycles to produce fatigue failure depends on the type of joints in stiffeners. A study was made by Jasper (7) on the service data on the wave-induced girder stresses on different ships covering a period of a few years. The wave-induced stresses added to the steady load stresses determine the life of a ship's structure.

Of the hulls repaired, many of these cracks are found in the middle of long side edge of a plate panel formed by shell longitudinals and transverse webs. The approximate dimensions of a typical panel are 84"x27". The restraint offered the shell at the boundaries of the panel approaches a rectangular plate with fixed edges. The bending stress at the long side edge is twice that of the middle of the panel for a distributed load. The plate stress introduced from lateral loading added to the primary stress in seaways is sufficient to cause these cracks. This may be looked upon as the combined stretching of the plate panel together with tensile stress from the working of hull bending. These cracks generally occur in shell strakes D and E amidships, Figures 1 and 2, where the plating is 11.47 lbs. HTS, which is lighter than other strakes. It is possible that the undercutting of the longitudinal welds contributes

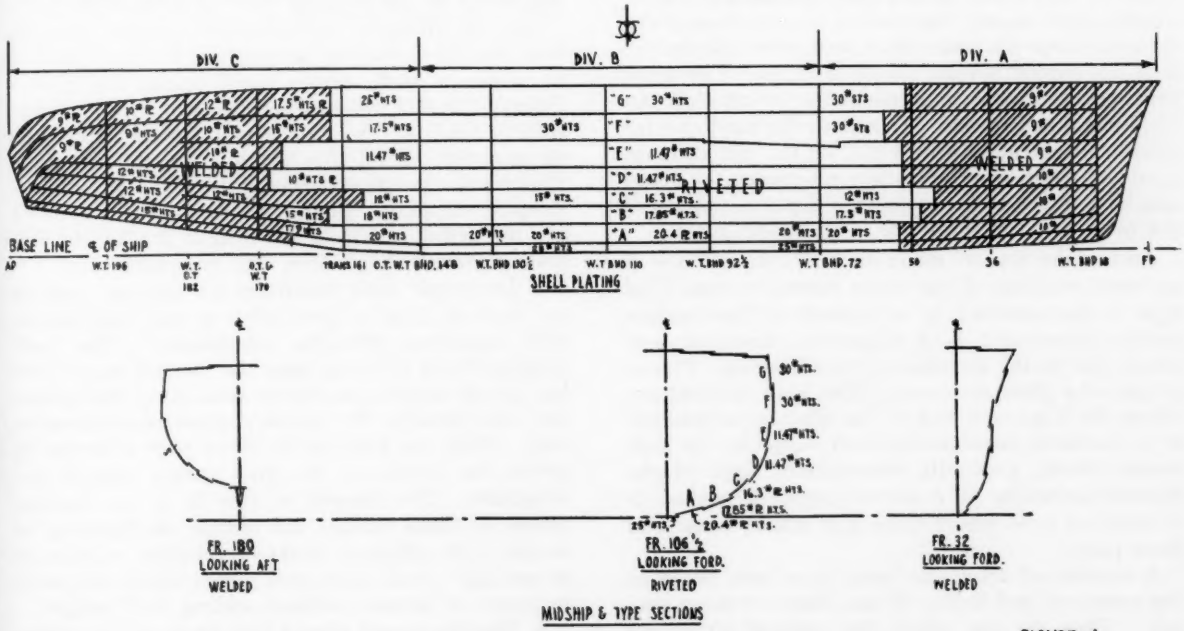

Figure 1—Typical Destroyer Shell Plating

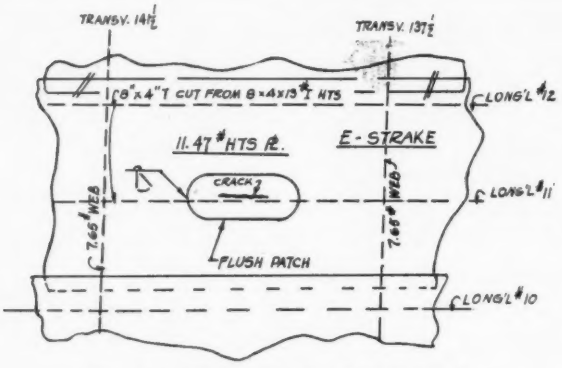

Figure 2—Typical Crack of Shell Panel

to the failure. The usual repair is accomplished by cutting a window with a suitable radius in way of the crack and flush patching with reinforced bevel butt weld. This is shown by sketch, Figure 2.

It is worthy to note that there were 33 shell cracks occurring on the transverse edges of an insert or doubler plate which is introduced to compensate for a shell opening. This plate, being twice the base shell thickness, is usually of octagonal shape and is shown by sketch, Figure 3. It is so arranged that the fore and after edges are transverse to facilitate shipfitting. The sharp shoulder thus formed between the base plate and the insert plate is a geometrical notch causing stress concentration. The outside fillet weld is insufficient to provide proper transition to ease the stress pattern. After many cycles of high alternating bending stress, fatigue in the weld becomes evident and the crack ensues. As a result, the crack in the weld propagates transversely and usually terminates in the base plate. It is fortunate that this crack progresses slowly and does not extend beyond the shell strake. The usual repair procedure is to safe-end the crack, chip out weld metal and reweld. To relieve the hard spot for stress concentration a fore and aft flat bar stiffener is added to improve the transition between the insert and base plates and increase the flexural rigidity of the plate panel in the wake of the insert plate.

Among the repairs made on hull cracks, there is an occasional one of the stress corrosion type. This type is characterized by a network of fine surface cracks progressing in a transverse direction perpendicular to the direction of tensile stress. Photographs of a plate specimen of this type of crack are shown by Figures 4 and 5. The plating, submerged in a corrosive environment and subjected to high tensile stress, gradually deteriorates until cracks become apparent. The normal repair procedure is to crop out area where these fine cracks occur and flush patch.

A number of cracks or holes have been noted in the coamings and baffles of sea chests of these vessels. They do not affect the general structural strength of a ship. Corrosion and erosion are the

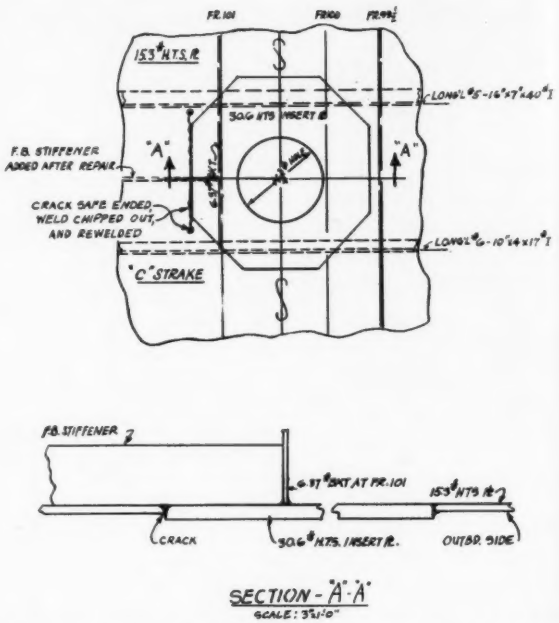

Figure 3—Typical Shell Crack at Transverse Edge of Insert Plate

principal causes of this type of failures. The damaged components are removed and renewed. No great difficulty has been encountered in these repairs since they are accessible from the outside.

Of the numerous hulls with cracks examined, there were only four cracks of the shell butts. This record speaks highly of the quality of welding and inspection by the building yards of these destroyers.

The hull cracks of destroyers so far noted have not been serious in that the propagation has been limited to within a shell strake itself, unlike the brittle cleavage type of cracks where the propagation starts with a notch in the source plate, tears across the through plate and finally terminates in the end plate. The crack therefrom frequently leads to a catastrophic casualty. Since periodic stress variations are the prime causes of the fatigue cracks, the following general conclusions may be drawn:

a. Destroyer shell scantlings for obvious reasons are made as light as practicable to suit longitudinal and transverse strength calculations. The shell strakes D and E, being near the neutral axis of the hull girder section, are lighter than other shell plates and are suitable for primary stress consideration only. With the high cyclic stress over a period of years, the cracks on the thin panels appear unavoidable. The remedy to this is to use heavier plates for these strakes and reduce the disparity of weight with adjacent strakes. Another solution is to use high yield alloy steel plates which are more resistant to fatigue without adding hull weight.

b. The shape and abrupt change in section of the insert plates for shell openings lend themselves to

Figure 4—Transversely Propagated Stress Corrosion Cracks

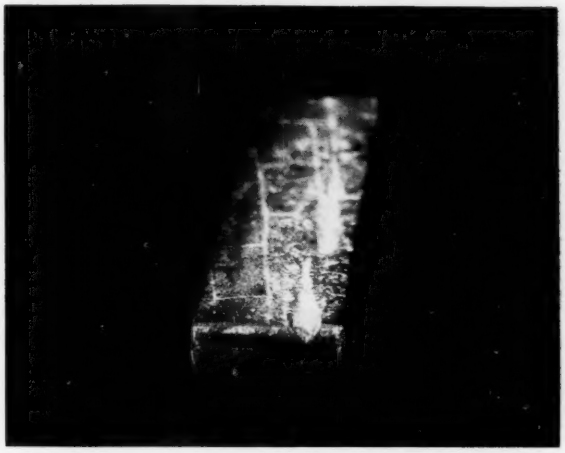

Figure 5—Sectional View of Stress Corrosion Cracks

stress concentration. The stress concentration factor increases two or three fold. A circular insert plate with periphery gradually tapered to thickness of base plate would appear more desirable. This would introduce some difficulty in fabrication and shipfitting and would increase shipbuilding cost slightly.

c. Improvements in hull preservatives and cathodic protection systems now in progress by different agencies would increase the resistance of the shell to corrosion to reduce stress corrosion type of cracks.

d. The welding technique of shell has reached a fine degree of acceptability, in that relatively few cracks have been attributed to poor welding. Shipyards employ the best and most experienced welders in the fabrication of the more important structural components, such as shell plating and intricate foundations.

e. Ships with light scantlings have never been known to break in two like the T2 tankers or Victory and Liberty cargo vessels. Fatigue cracks on destroyers are after all, nuisance cracks, not enough to cause severe damage but sufficient to require constant upkeep and repairs. The fact still remains that a destroyer will become incapacitated to carry out its military mission while under this type of hull repair. It further ties up drydocking spaces which could be employed for more necessary work.

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"U. S. NAVAL INSTITUTE PROCEEDINGS"

THE U. S. MERCHANT MARINE AND OBSOLESCENCE

ACKNOWLEDGEMENT

This article, by Captain E. B. Perry, USN (Ret.), was published in the January 1958 edition of the "United States Naval Institute Proceedings".
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Is the U. S. Merchant Fleet truly and rapidly approaching obsolescence? In the few short years since our present fleet of fine dry cargo ships was delivered from the builders' yards, have the arts and sciences of ship design and construction so advanced that we now are faced with an obsolete U. S. Merchant Marine? If this be the case, then we are in a sad situation with respect to our foreign waterborne commerce carriers and our dependence upon a strong and sufficient naval and military auxiliary capable of service in time of war or other national emergency.

Recently we have been bombarded with literature and speeches to the effect that unless we immediately embark upon an all-out program of new construction, starting with the year 1959, the U. S.-flag private owners of dry cargo, passenger, and combination vessels will be operating a fleet of obsolete ships. We are advised that this soon-to-be-outdated fleet, privately owned, consists of some 1,054 vessels; 717 dry cargo and passenger-carrying vessels and 337 tankers. The Government-owned (reserve) fleet consists of some 2,010 vessels, making a total U. S. Merchant Marine of 3,064 vessels with a combined gross tonnage of approximately 23,611,000 and a combined deadweight of about 33,216,000. Considering only the dry cargo and passenger-carrying vessels, we find that about 300 are being operated on essential foreign trade routes by sixteen owner-operators under the provisions of operating-differential subsidy contracts. About 417 vessels are being operated in our off-shore commerce without the benefits of subsidy: tramping, chartered, or in the domestic or intercoastal trades. Six of the owner-operators of the non-subsidized fleet, owning a total of about 109 vessels, are presently seeking subsidy contracts after having become convinced that they can no longer compete with foreign-flag vessels without Government aid. The American Tramp Shipowners Association, a group of owners of Liberty-type ships included in the 417 vessels above noted, is pressing for the enactment of a law which would make their vessels available for subsidy aid.

Obsolescence, as it affects the owners, applies only to those dry cargo and passenger-carrying vessels which are being operated under the provisions of operating-differential subsidy contracts—the 300-vessel group. Obsolescence-replacement is one of the burdens imposed upon the owner who accepts subsidy aid. This fleet of vessels which are said to be approaching obsolescence consists of four superliners, a sprinkling of the recently constructed Mariners, a few Victories, and various C-class vessels. The Maritime Administration (hereinafter called Maritime) has made an arbitrary determination that all vessels operating under subsidy, except the AP2 Victory, have a useful subsidized life of only twenty years and at that age automatically become obsolete. The AP2 Victory, a better ship than some of those of the C-Class, has been granted a useful subsidized life of only fourteen years—the reasoning behind this determination not being too clear. Under this

"obsolescence" ruling, the C-class vessels will reach the ends of their useful subsidized lives during the period 1959 through 1967; the great bulk of them prior to 1964. The AP2 Victory will reach a youthful fourteen years of life on or before 1959; the superliner *America* by 1960; the AP3 Victory on or before 1967; the superliners *Constitution* and *Independence* by 1971 and our Queen of the Seas. the blue ribbon holder *United States,* will have become *obsolete* by 1972. "Obsolescence," as applied, has nothing at all to do with the condition of the vessel, her design, construction, or her ability to do the job in which she is engaged. It is merely an age limit which has been assigned by rule of thumb to the vessel of the subsidized fleet.

Obsolescence is not a term which is new to the Navy, and it may be that Maritime has followed the Navy's footsteps. Naval ships do have to keep in step with, or ahead of, the techniques of warfare. Unfortunately, those techniques have "improved" by leaps and bounds. This has required that the design and construction of naval vessels be quite fluid and within twenty years time a naval vessel might be completely out-of-date both as to purpose and construction. On the other hand, the dry cargo carrier continues to have the same job—to lift cargo as efficiently as possible and the problem has not changed a great deal. It is quite obvious that the same life expectancy need not apply to both the merchant and the combatant ship. The Internal Revenue Service has adopted the twenty-year plan for the amortization of merchant vessels, including the AP2 Victory but excluding the Liberty. The Liberty has at various times been considered to be a five-year ship or a ship of less useful life. Twenty years, a nice round figure, seems to have hit the popular fancy.

Since this "twenty years down and out" ruling applies only to those vessels which have been authorized for subsidy, this discussion will be limited primarily to subsidized vessels. No merchant vessel truly becomes obsolete, automatically, when it has reached twenty years of its life. There are many vessels in service on the Great Lakes and quite a few along our coasts which have been performing faithfully for periods of up to fifty years. The Liberty ship was considered by many to be obsolete even when it was on the design board. Liberties, built by the Government and then offered for sale, went begging for years; few private owners cared to purchase them. Today, on the domestic market, the Liberty is selling for half as much again as the Maritime asking price. On the foreign market it is selling for about double that amount. Several Liberties have been modernized into fine, fast ships. The *obsolete* Liberty is the backbone of the tramp fleet and is working on some of the liner trade routes. The Liberty may be obsolete in theory but it still is a strong contender.

Under the obsolescence ruling, the logical replacement for the standard C-2, AP2, and AP3 Victory-types which go to make up a considerable part of our present dry cargo subsidized fleet might be a vessel similar to the Maritime-proposed Clipper. Considering an average trade route of about 12,000 miles, round trip, and with the vessels bunkered for the round trip, a comparison of the C-2 and the Clipper, as given in Table I, will enable us to understand some of the problems imposed by an enforced replacement program under the cloak of obsolescence.

Considering some of the advantages to be gained by the operation of this replacement Clipper over the *obsolete* C-2, we find that the Clipper can lift about 10,255 deadweight tons more than the C-2, an increase of some 21%, and can stow about 699,000 more cubic feet of cargo per year, an increase of about 19.5%; however, we will not necessarily receive both the advantages of space and deadweight lift. The Clipper will only be 'full and down' when the cargo mix is such that the cargo stows at about 71.5 cubic feet to the ton. Cargo that stows in excess of 71.5 cubic feet to the ton will fill the space of the ship without putting her down to her marks. Cargo that stows at less than 71.5 cubic feet to the ton will put the ship down to her marks but the ship will sail with unfilled space. Speed may be desirable if we can afford it and if we can make some use of it. A faster vessel will sometimes attract a better paying cargo. In this case we have found that the saving of time by the Clipper on the outward leg of the voyage—and this is what might attract cargo—is only about two days, which is not much of an advantage to the 18-knot vessel.

On the other side of the slate, we have decidedly more vessel to man and to maintain. She will require more dock space and deeper water (sometimes an embarrassing requirement). We have a heavier ship to push through the water; pilotage fees will be increased; the port maneuvering problems are somewhat increased; and she will have a much higher registered tonnage on which to pay port dues, canal tolls, drydock charges, loading and unloading

TABLE I

	C2-S-B1	*Clipper*
Approximate cost to build	$2,736,600	$9,000,000
Approximate cost to Owner	$958,000	$4,500,000
Length overall	459'3"	496'
Beam	63'	73'
Full load draft	25'9"	28'
Full load displacement, tons	13,860	16,900
Light ship, tons	4,660	6,000
Deadweight, tons	9,200	10,900
Bale cube, cubic feet	546,000	600,000
Cube factor from above	59	55
Gross tons	6,200	10,000
Net tons	3,500	6,000
Horsepower	6,000	11,000
Speed	15.5	18
Deadweight available for cargo, tons	7,550	8,380
Turnaround days	55.2	50.8
Voyages per 360 day year	6.5	7.08
Maximum deadweight lift per year	49,075	59,330
Maximum bale cube per year	3,549,000	4,248,000

expenses, *etc.* The scale of wages paid to the ship's officers goes up with the tonnage-horsepower. The fuel costs will be increased by one half, and we have to move an extra tonnage of fuel which is not paying revenue. The greatest problem which confronts the prospective owner, however, is the initial cost and the increased operating costs of the replacement vessel. The C-2 is worth, at today's market, about $1.35 million and the owner would hope to sell the ship, or turn it in to Maritime (to go into the back channel) for about that price. With the benefits of a construction-differential subsidy, he might hope to acquire the Clipper for around $3.15 million ($4.5 minus $1.35 equals $3.15 million). The prospective owner immediately is faced with a refinancing problem; he must increase his net worth and his working capital. He has to find some money of his own or locate some citizens with both money and a confidence in the future of the American Merchant Marine. He will do neither unless there is some promise of a reasonable financial return for the monies invested. His fixed charges and his operating costs will be greatly increased. To offset them we have found that the replacement vessel has a maximum advantage of only about 20% revenue-wise. It is clearly evident that something—or someone—has got to give if the owner is to stay in business. The expensive replacement ship has got to earn a lot more revenue or receive a substantial increase in subsidy aid.

The replacement vessel must seek the same general run of cargo which is being lifted by the vessel which it replaces, and at the same rates. It must seek this cargo in competition with foreign-flag vessels, vessels which are reported to be operating at about one-half the cost of the U. S.-flag vessels presently on the trade routes. Unfortunately, American shippers are not too concerned as to whose flag flies over the vessel which carries their commodities. A powerful group has been attempting to have rescinded the requirement that at least fifty per cent of our foreign aid programs be carried in American bottoms. The American shipper is concerned that his commodities shall be moved at the least cost to him per ton-mile, the saving to be spent by the foreign purchaser for a few more American shipper commodities. As was noted above, in certain cases a special cargo might be attracted to a faster ship provided the faster ship is actually to arrive at the desired port first. If the United States steps up the speed of the subsidized fleet, the foreign-flag operators will probably find it desirable to step up the speed of their vessels. We have seen an indication of just that on the transpacific runs where some of the twenty-knot Mariners have made their appearance. Increasing the speed of our ships may simply result in a rat-race, at great expense to everybody concerned, with the balance of 'attractiveness' being maintained. It is quite evident that the replacement vessel with only a 20% advantage cargo-wise and handicapped by greatly increased costs is going to have to be heavily subsidized.

Having considered some of the problems of the operator when he is pressed to replace his existing vessels, the question naturally arises as to whether those existing vessels are truly approaching obsolescence or whether some other worthwhile purpose is being served under the cloak of obsolescence. The merchant vessels flying the United States flag are under the cognizance of some sixty or more Bureaus and other subdivisions of the Federal Government, about nineteen Departments and independent agencies; and are bound by the several International Conventions such as Load Line, Safety of Life at Sea, Radio-telegraphy, Assistance and Salvage at Sea, and Sanitary. They are frequently and regularly subjected to rigid inspections by the U.S. Coast Guard, the American Bureau of Shipping, the U. S. Public Health Service, the Federal Communications service, and the Maritime Administration, to name a few. Our ships are generally conceded to more than meet all of the requirements for safe, well-equipped, seaworthy vessels. Each and every subsidized vessel is, today, undoubtedly a better vessel than it was the day that it was delivered to the owner. There have been no great technological advances in the art of ship design or construction during the past twenty years—if we except the proposed atom-powered ship and it is not believed that the merchant service is quite ready for that type of propulsion. *Our present fleet of subsidized vessels is not approaching obsolescence set by regulation.* If you have any fears that the U. S. Merchant Marine is coming apart at the seams or is being driven from the seas by more modern foreign flag vessels, you may rest assured that your fears are not well grounded. If the military has a need of the U. S. Merchant Marine today or tomorrow, it will be found that it is willing and able.

Just what is the purpose of this expedited replacement program which is being attributed to obsolescence? Maritime is charged with the responsibility of seeing to it that the U. S. Merchant Marine is composed of the best-equipped, safest, and most suitable types of vessels, constructed in the United States. In furtherance of that mission, Maritime is continually trying to up-grade the fleet of vessels operated by the private owners holding subsidy contracts, for that is the only place where pressure may be applied. Maritime appears to be stressing ease of cargo handling and speed. Many schemes and ideas are in the experimental stage with respect to expedited and more economical cargo handling: palleting (not a new idea), container ships, roll-on-roll-off ships, and fishy-back being examples. Thus far most of those ideas apply to vessels in our domestic trades. Certain trial rigs have been installed in some of the modernized Liberties. Should some progressive and truly worthwhile development result, proved by experience, it probably could and

would be incorporated into ships of our existing fleet.

Maritime has established the policy that no replacement ship will be considered suitable for subsidy payments unless it shall have a speed of eighteen knots—except where the operator can furnish convincing proof that a somewhat lesser speed is more desirable for some particular trade route and service. Under certain circumstances, it should not be very difficult to demonstrate that a lesser speed will be advantageous to the owner. Under many circumstances high speed in a dry cargo carrier offers no advantages to the operator commensurate with the greatly increased costs. The Mariners were built, operated under General Agency (many serving MSTS) for a few months, and then they went into the back channels. Maritime put on a high pressure sales campaign to get the Mariners off the Maritime payroll and into private hands at work on the trade routes. The owners were not eager buyers until a very competitive price was set on the ships during a boom in shipping. Then the Mariners were purchased by some operators who needed big, fast ships for conversion to passenger-type ships or by those who were faced with some replacements for operation over trade routes where the distances were great and the twenty-knot speed might be able to pay off. As dry cargo carriers, the Mariners are conspicuous by their absence on the short and moderately long trade routes.

It is generally considered that Maritime has gone to the obligatory eighteen-knot speed requirement at the insistence of the Navy. As naval auxiliaries, it might be highly desirable to have some eighteen-knot vessels. Certain of the trade routes lend themselves to eighteen-knot vessels; we have some fine eighteen-knot vessels and we are going to get some more. In cases where more speed is built into the vessel than the owner requires, the greater cost resulting from the increased installed horsepower becomes a "defense feature," and the Federal Government must pick up the tab. In these days of high speed submarines, very high speed combatant vessels, and aircraft, it may well be that a lesser emphasis should be placed on a small increase in the speed of a merchant-type vessel; a vessel which *might* someday have to serve with the armed forces. It does appear to be rather questionable to set up a rigid requirement of eighteen knots for every subsidized vessel regardless of the commercial operation in which that vessel will be engaged.

It is essential that our shipyards shall be kept employed in a long range, continuing program of new construction. When the emphasis was first placed on obsolescence based on age, the shipyards had just about completed the Mariner program and they were hungry for work. The obsolescence program has come to their rescue. Recently it was reported that there were some 65 ships under construction or on order. The new construction program in sight represented an expenditure of over $700 million. Twelve of the subsidized lines had full or partial obligations to construct a total of 172 vessels as replacements for their existing ships. The established yards were so busy that rehabilitation of some of the Maritime-owned closed yards was considered.

If the twenty-year ruling had remained in effect—and had the Congress appropriated sufficient funds to implement it—it appears that within the next seven years there might have been constructed around 250 vessels plus a superliner to replace the *America* (at an estimated cost of $115,000,000 for this ship alone). Such a program would easily have run into an annual expenditure of around $330,000,000. Undoubtedly some of the operators who are currently seeking Government aid will obtain subsidy contracts and then their vessels will come under the obsolescence replacement requirement, thus increasing the number of vessels and the costs. It has been estimated that it would cost about $27,000,000 to replace the vessels of one of the applicants and about $285,000,000 to replace the vessels of another—and they are only two of the six who are seeking subsidy contracts. A great part of that cost would have had to come out of the tax dollar.

All of us want the U. S. merchant fleet to be composed of the safest, best-equipped vessels of the most suitable types for the services which it is expected that they will be required to perform. Our National Budget has reached that height where even its shadow becomes frightening. We are becoming economy-minded and inflation-conscious. It is recognized that steamshipping is a business and that any business must be so conducted that it may return a reasonable profit if it is to be attractive for investment, be the funds private or Federal. Our foreign trade is in competition with foreign-flag vessels and those vessels can be built and operated at a fraction of the costs of the U. S.-flag vessels, requiring that our ships receive Government financial support. More expensive ships require more subsidy aid. It appeared questionable whether we could afford the luxury of the wholesale ship replacement program which was facing us plus a greatly increased operating cost which would be generated thereby. Congress has answered that question for the time being. By severely cutting the requested appropriation, the new construction program has been checked. Congress has appropriated $3,000,000 which is to be added to a $94,500,000 carryover, thus making some $97,500,000 available for new construction for fiscal 1958—a far cry from the contemplated program but still a sizeable sum of money.

It would appear that the time has come when our vessel replacement program might well be based upon the *required* replacement of ships. A vessel might not be a suitable type of carrier on some one trade route, for reasons of speed, size, deadweight-

bale relationship, cargo handling arrangements, or luxury appointments, but it might be a highly desirable and efficient carrier on some other trade route. There appears to be no good reason why the vessel should not be operated on such a trade route rather than moved into the back channel. Obsolescence-replacement should be based upon the ability to perform rather than on numbers of years of life. We may, and we must, place a considerable dependence upon the owners whose business it is to operate ships to implement such a program. The steamship business is more competitive than most and the owners are vitally concerned that they shall have the proper tools with which to conduct their operations successfully and at a reasonable profit. Any steamship line that attempts competitive operations with obsolete ships will not long be flying its houseflag. There should be an incentive to the owner who is willing to build a better-than-is-required vessel. A regular and continuing program of replacement, based upon the performance of the ship and its fitness to do its job, rather than an arbitrary span of life, will make for better vessels, more economy, a more assured long-range fleet and a sounder new construction program for our shipyards. It will get away from blocs and periods of feast or famine. It will allow new ideas and practices to be progressively built into our ships as they follow each other out of the builders' yards.

It is assured that there are only so many tax dollars which will be made available for ships and shipping. In return for our Yankee dollars we want to have available the best possible fleet, both as to numbers and characteristics. Under the terms of the Merchant Marine Act, 1936, the Navy is an interested party in the development of the merchant fleet. A very expensive ship replacement program, coupled with the necessary increase in aid for the operation of that more expensive fleet, might well have resulted in a smaller fleet of merchant type vessels which would have been available to us, if and when needed.

Congress has been, and is, very sympathetic to the needs of the steamship industry, both shipbuilding and ship operation. A replacement program based upon the best utilization of our ships, on a realistic need of new vessels rather than a requirement based only on age, would undoubtedly win warm support. Let us not build a straw man, Obsolescence, and then knock ourselves out in trying to tear it down.

The U.S.N.S. COMET, recent addition to the fleet of the Military Sea Transportation Service, is specially designed to provide sea transportation for large vehicle lifts. Also capable of carrying normal cargo in a conventional manner, the ship is fitted with regular cargo handling equipment. Vehicles may be loaded under their own power over portable ramps at the stern and on the sides. The "roll-on-roll-off" capability provides an extremely short turn-around time for vehicular cargo. The 500-foot ship will make 18 knots. A flush deck ship, the engine spaces are located amidships and incorporate a novel arangement permitting vehicle ramps between decks in way of the main machinery spaces.

—from "Marine Engineering/Log," March 1958

BORISLAV A. DJODJO

AN EFFICIENT PROCEEDING OF TAKING DOWN THE LINES DRAWING FROM THE SHIP HERSELF

THE AUTHOR

graduated from the Faculty of Mechanical Engineering, University of Belgrade in 1951. He was commissioned to research work at the Ship Section, Mechanical Engineering Institute of the Serbian Academy of Sciences, first as research assistant and from April 1956 on as research officer. He was responsible for Marine Engineering in general and Torsional Vibrations in particular. He took part in designing a number of new vessels, took out some patents and wrote some papers. He holds membership in the Society of Engineers and Technicians of Yugoslavia and in the Yugoslav Society for Applied Mechanics.

It happens very often in shipyard practice that the lines drawing has to be taken from the ship herself. This task is especially met when altering or repairing a ship whose plans are not available. As a matter of fact, such cases were particularly often in the period immediately after the war, but they occur permanently in some shipyards, too.

Beside the alterations and reparations to ships, the same task can be set for mere documentary purposes; the checking of the stability and propulsion characteristics for a ship whose plans are not available; making specific measurements of a ship's hull and so on.

However, although this task springs not too rarely in shipyard practice it is rather astonishing how primitively it has been performed so far. The usual practice is that of marking off two guiding-marks in the hold and of measuring the distances from them to some points on the frame. These measurements are taken to a drafting board later, and with a compass set to scale of the dimensions, arcs are struck on the paper giving points through which to run the curves of the sections. This method is applied mainly for the measurements from the inside of a ship's hull, but sometimes similar outside measurements are made, too.

Another method of taking down the data for the lines drawing is that of fixing in the center line of the ship a vertical pillar with the horizontal guides through which measuring rods are pushed and so the half breadths of the frames are measured on different drafts.

The shortcomings of the displayed methods are evident: first of all not a ship's line as a whole is taken down, but only some points of it. Then the measuring itself of the distances of these points from the guiding-marks, since being performed in rather difficult ship conditions, is liable to many human and other variable errors. The guiding-marks are a problem by themselves. The transfer of these marks from one close compartment into the other is especially troublesome in the peaks and adjoining compartments where both the deck and the keel are considerably curved. Generally speaking the methods can be designated as indirect procedures, the lines coefficient tables being the intermediate links between the ship and the lines drawing as the end of the procedure.

Nevertheless, the displayed methods have been persistently applied for many decades. The matter as a whole has been considered as troublesome but not significant enough to deserve special consideration.

So far as the author is aware, only one attempt has hitherto been made to lay down a more modern basis for the procedure of taking down the lines of a ship's hull. This was made in USSR and that only in the most recent time. A photogrametric method was developed there whereby the frames to be taken down are first colored and then the whole ship is photographed so that by photogrametric methods the lines of the ship's hull can be reached afterwards much in the same manner as the geographical maps are made. It seems that this method has proved to be rather reliable and that it is striking root further in USSR. A book describing the procedure in full length appeared recently there (Kovtun, A.D.: "Primenenie fotografii dla sjemki s naturi obvodov korpusov sudov i grebnih vintov," Sudpromgiz, Leningrad, 1956).

As a matter of fact, the photogrametric method is again an indirect proceeding, the snapshots and a series of unavoidable auxiliary means being the intermediate links between the ship and the end drawing.

Another new line of approach to the task of improving the proceedings of taking down the lines of a ship's hull will be the subject of this paper. The matter is about a direct proceeding which was launched recently in Yugoslavia by the present author.

The line of approach is a very simple one: sections of the ship may be taken down by means of a pantograph. Hence the method is necessarily a direct one: there are no intermediate steps between the ship and the lines drawing, the lines being drawn "on the spot."

Nevertheless, although both the basic idea and the pantographic drawing itself appear to be very simple and to require nothing more than a mere routine, many difficulties press against the realization of the mentioned idea in this field. Some of them are a matter of principle, while the others are of technical nature.

The major obstacle from the first group is the fact that the ship's hull is a voluminous, hence a 3-dimensional body, while all the normal lines of a ship are 2-coordinate, hence plane curves. Thus the application of a 3-coordinate pantograph ("relief"-pantograph) is of no use here. To obtain a direct method 2-coordinate pantograph has to be used. However, although the use of such a pantograph offers no difficulty (at least in the principle) if only a separate ship's section has to be taken down, the thing stands otherwise if the matter is about a body. Namely if a voluminous body has to be determined by a system of plane curves (all of which are parallel to a reference plane), then not only the curves as such have to be taken down very precisely, but also the relative positioning of them must be determined completely. In order to achieve that a constant position towards an arbitrary reference line must be retained by the pantograph when taking down the lines by which the form of the body is to be determined.

For example when taking down the cross sections of a ship's hull the best reference line is the center line of the keel. When the pantograph is periodically shifted along the ship with a view to take down all the necessary cross sections, then not only the distance l_0 (Figure 1) and the angle ζ_0 (which determine the position of the pantograph towards the hull) are to be kept constant, but also the angle α_0 which represents the inclination of the pantograph itself against the line l_0 must be kept constant. It is hardly necessary to say that the plane of the cross section to be taken down and the working plane of the pantograph must coincide thereby.

If all the mentioned conditions are fulfilled, then not only the individual cross sections will be rightly taken down, but also their relative positioning on the pantograph drawing board will correspond just to the actual one on the ship herself. The sum of these conditions (constancy of l_0, ζ_0, α_0, coincidence of planes) will be spoken of as the positioning of the pantograph. Hence this is an additional requirement which is entailed just by the fact that a voluminous, hence a 3-dimensional body, has to be determined by a 2-coordinate pantograph. Instead of the third coordinate, there is the requirement of the positioning of the pantograph.

The difficulties of the technical nature are as follows:

If a large pantograph of the same design as the small table pantographs (Figure 2) is constructed for our application it will be very clumsy and heavy. The weight of the linkage itself will be so considerable that the operator will not be able to support

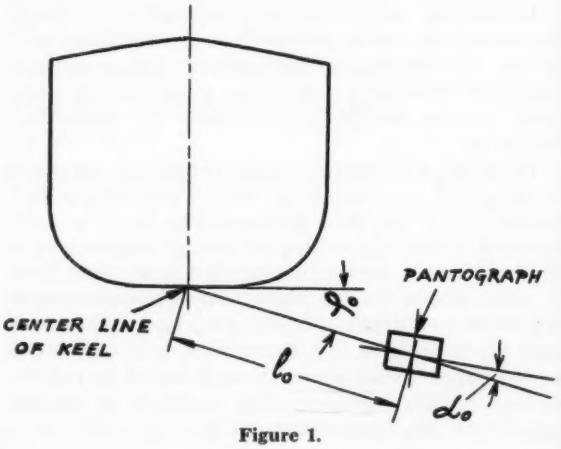

Figure 1.

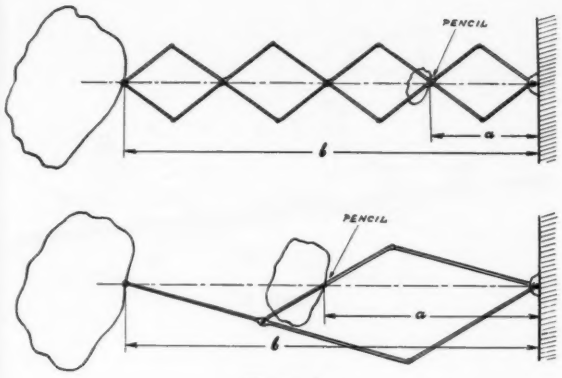

Figure 2.

its outer end which has to be moved over the ship's plating. Besides this weight will cause a considerable inflection of the linkage which will necessarily induce some deformations to the graph which is being drawn by the pantograph. Many shiftings of the pantograph along the ship (for the purpose of taking down all the necessary cross sections) will cause the linkage to become loose soonly, the pantograph becoming thus unservicable.

Besides the linkage pantographs cannot afford a sufficiently low reduction ratio. Reduction ratios down to 1:10 or so which are usual with the table pantographs are quite insufficient for our application where the ratios of 1:20, 1:50, 1:100 or even lower ones are necessary.

Hence it is evident that quite a new pantograph has to be designed for the realization of the pantographic proceeding of the taking down of the lines of a ship's hull. Its main feature has to be that what comes in lieu of the linkage must be very light. Whereas the linkage with the table pantographs could be leaned against the table in many points, the element which in our case comes instead of it is hung freely in space between the ship and the pantograph drawing board. That is one reason more for it to be very light. Besides this fact induces us to speak of the new pantograph as the "space"-pantograph in contradistinction to the "table"-ones. (It will be remarked that in spite of its name the "space"-pantograph is no "relief"-pantograph, i.e., a 3-cordinate pantograph; it remains to be a simple 2-coordinate pantograph.)

The new pantograph is shown in Figure 3. Cable 7 is pulled through a radial hole in the horizontal axle 3 and after having been wound on the wheel 9 it is fixed to it. The axle 3 bears a light rule 4 which is easily revolvable (ball bearing) about it. The weight of the rule is balanced by the counter-weight 5, so that only negligable ball bearing friction has to be overcome to get the rule revolving about the axle.

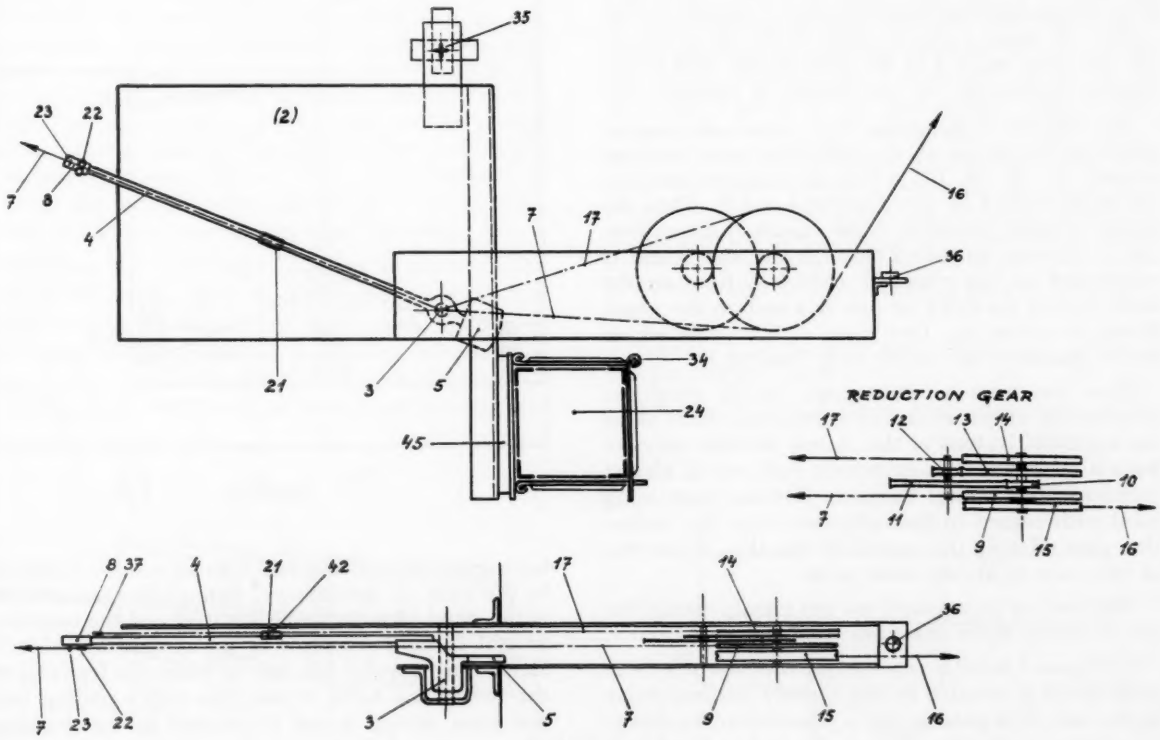

Figure 3.

On the top of the rule 4 there is a head 8 which bears two calibrated slots, one of which is horizontal, while the other is vertical. The free end of the cable 7 is pulled through these slots. The cable 7 is kept tight on behalf of the operator which pulls its free end outwards while the wheel 9 is pulled by a special cable 16 in the opposite direction (cable 16 is wound on the grooved wheel 15 and is fixed to it; the wheels 9 and 15 are steadily connected; free end of the cable 16 is passed through a pulley gear 18 which is suspended on a stand 19 and then is charged by the counterweight 20 (see Figure 4).

Thus on behalf of the tightness of the measuring cable 7 and the mentioned slots which are precisely calibrated to it, every movement of this cable in its vertical plane is rightly transmitted to the rule 4. The angle through which the rule 4 is revolved about the axle 3 is the same as the angle swept by the cable 7. Hence the first coordinate, i.e., the angle, is yet realized with our pantograph. It is evident that this pantograph is based on the polar coordinate system whose origin is the axis of the axle 3. Thus it remains only to provide means for the second coordinate of the system, i.e., the radius. Its measure is the extension of the measuring cable 7, i.e., the distance from its free end to the axis of the axle 3. But to get the reduction this extension must be reduced somehow and then delivered to the slider 21 (see Figure 3) which slides the surface of the rule 4 looking into the drawing board 2 of the pantograph. Thus the slider 21 is moved along the rule 4 in a determined proportion to the extension of the cable 7. It bears a pencil which draws the graph on the drawing board 2 of the pantograph, and so the second coordinate, i.e., the radius, is realized, too.

The moving of the slider 21 in a reduced scale is achieved by means of the reduction gear (toothed wheels 10, 11, 12, 13) which is included between the wheels 9 and 14 (see Figures 3 and 5). Then the slider is simply included in the circuit of the endless cable 17 which is pulled through the axle 3 and is suspended on the wheel 37 (which is fixed on the outer end of the rule) on one side and on the wheel 14 on the other one. One point of this cable which never abandons the wheel 14 is fixed to it.

Thus we have a pantograph which does not possess any of the aforesaid drawbacks of the table pantographs. Instead of the clumsy linkage here we have a cable which is extremely light and is almost mandatory for doings in space. Besides there is no limit with regard to the reduction ratio, the reduction gear offering the possibility for the adjustment of this ratio in a very wide range.

With such a pantograph we can rightly tackle the job of taking down the lines from the ship herself.

In Figure 4 there is represented the case of a river craft which is situated on the slipway perpendicular to the rails. The pantograph is situated on the downward slope at the foot of the ship and is fixed to a horizontal beam 24 which is provisionally fastened to the rails of the slipway. Behind the beam there is the stand 19 with the pulley gear and the counterweight 20 for the tension of the measuring cable 7. Hence the operator has only to move the free end of the measuring cable 7 over the ship's plating and the cross section which is situated in the working plane of the pantograph will be drawn automatical-

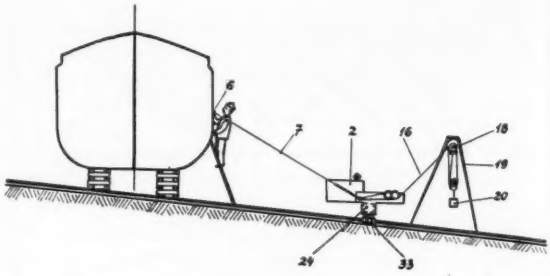

Figure 4.

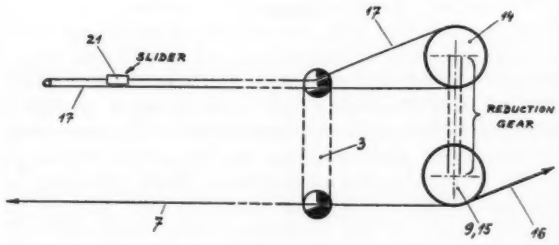

Figure 5.

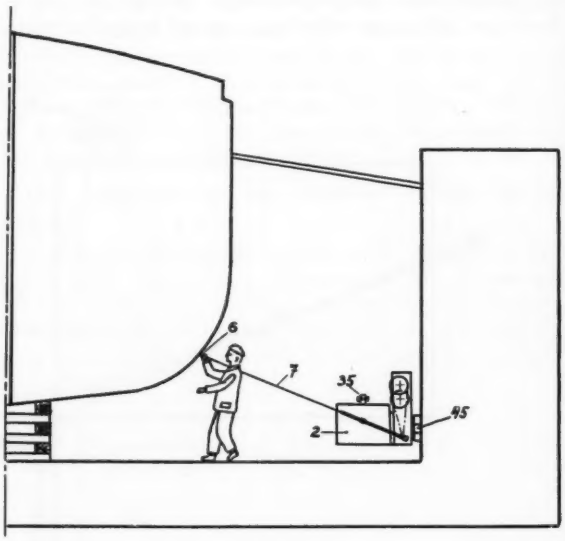

Figure 6.

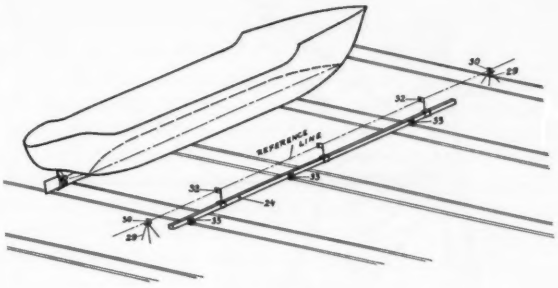

Figure 7.

ly on the drawing board ("working" plane is the vertical plane in which the cable 7 is being moved). After shifting the pantograph several times along the beam 24, the whole body plan of the ship will be drawn on the board.

The case of the river craft was shown first only for the purpose of clarity. Namely the disposition of the ship, pantograph and the counter-weight stand is normal here. Besides it may be here remarked that the pantograph must be placed relatively low so that the cable 7 can approach freely both the bottom and the side wall of the ship.

The disposition of the mentioned elements is mainly the same in the case of the ship in the dock (Figure 6). The counter-weight stand (it is not drawn in Figure 6) is placed on the bottom of the dock near the pantograph. The after part of the pantograph (portion pertaining to the reduction gear) is revolved by 90 degrees in order to bring the pantograph nearer to the inner side-wall of the dock. The pantograph is fixed to this wall by means of the screws which are fixed into it once and for all. The horizontal row of these screws is laid rather low so that the axle 3 of the pantograph is pretty well below the keel of any ship to enter the dock.

Whether the pantograph is fixed to the beam 24 laid down on the rails of the slipway, or to the screws on the inner side-wall of the dock, or even to an independent stand which is then shifted along the ship, this connection is effectuated always by means of a clutch 45 which enables both small translations and rotations of the pantograph against the support. This is needful for the purpose of the precise positioning of the pantograph towards the ship.

The positioning itself is effectuated in this way:

Prior to the application of the pantograph a reference line is marked by one light beam (practice similar to that of aligning the shafting of the ship) which is set strictly parallel to the center line of the keel (light source, sight-holes and other things are put on two separate stands 29 and the beam 24—see Figure 7; similar provisions are made in the dock, too; in precise positioning of the reference line a theodolite can be used).

When later on the pantograph is being placed against successive frames it is always looked after the sight-hole 35 of the pantograph (see Figure 3) which must lie in the reference line. Water-level 36 must always indicate the same position of the pantograph, too.

Hence the mentioned clutch 45 of the pantograph is provided just for the purpose of enabling the adjustment of the pantograph against the reference line.

Thus what we specify as "the positioning of the pantograph" is both the marking of the reference line and the adjustment of the pantograph against it.

As to the reference line itself, it is chosen quite arbitrarily. It must be parallel to a known, straight and preferably characteristic line of the ship herself (which moreover may be hypothetical) and that is all. According as this line is perpendicular to the transverse, longitudinal or horizontal planes of the ship, the drawing on the pantograph's table will be respectively body plan, profile plan or half breadth plan. For the determination of the ship's lines it is quite sufficient to take down only the body plan wherefrom the other plans can easily be drawn out in the drawing office. Thus in the practice one reference line, preferably that which is parallel to the straight portion of the keel center line, is quite sufficient.

Turning now to some more significant details of the pantograph itself.

There is no use of the precise positioning of the

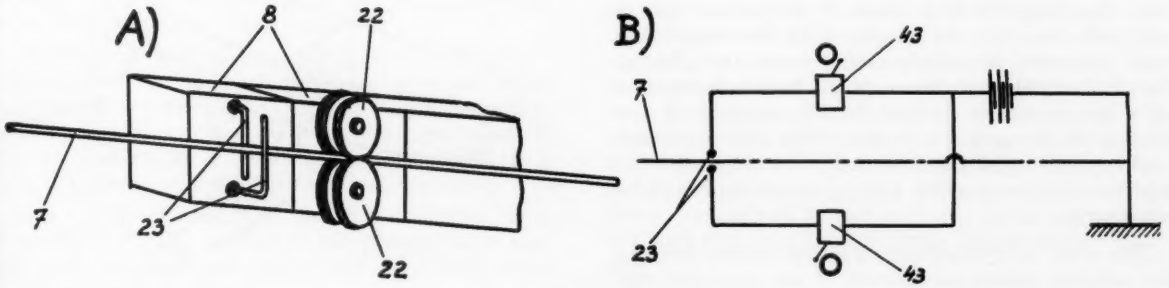

Figure 8.

pantograph if the measuring cable 7 is allowed to get out of the "working plane" of the pantograph. In order to frustrate this departure, the mentioned two slots on the head 8 of the rule 4 of the pantograph are constructed in a specific way.

In Figure 8 A there are two wheels 22 by the grooves of which a horizontal slot is formed. The height of this slot is equal to the diameter of the cable 7 while the breadth is somewhat larger. Hence any vertical movement of the cable 7 is rightly transmitted to the wheels 22, i.e. to the rule 4, while practically there is no hindrance by the horizontal slot for the cable 7 to move horizontally.

Just the reverse is the case with the vertical slot. It is formed by two pins 23 which moreover are included in two electrical circuits (Figure 8 B). Two bells 43 which are included in these circuits (the whole circuitry is fixed to the frame of the pantograph) are of quite different sounds. As distinct from the horizontal slot the cable 7 is not completely cramped for horizontal movement by the vertical slot as it was for the vertical movement with the horizontal slot. The interspace between the pins 23 is next to nothing larger than the diameter of the cable 7. Hence if the cable 7 is just in the middle of the interspace there is no contact between that cable and either of the pins 23; bells 43 are silent and the cable 7 lies in the working plane of the pantograph. However, the least departure from this plane is rightly warned by the ringing of one of the bells 43, and—due to different sound of rings—the operator rightly knows to which direction to move the cable 7 in order to bring it again in the right position.

The drawback of all the outside measurement methods is that the measurements are made only to the outer surface of ship's plating whereas the inner surface should actually be reached if a lines drawing is the aim of the job. Even the modern photogrametric method is handicapped by this shortcoming, too. The allowance for the thickness of the plating can be effectuated by this method only additionally in the drawing office.

However, the pantographic proceeding is quite free from this imperfection. A steel ball 6 (Figure 9) is attached to the free end of the cable 7. The ball is held by the operator and is slowly moved over the ship's plating. Thus if the pantograph is adjusted normally the graph on its drawing board will represent the ship's section with the plating. But if the cable 7 is drawn in the ball 6 (by means of a simple screw device) by the amount of the plating thickness δ, the graph on the drawing board will represent just the bare ship's section so that no additional allowance for plating thickness δ will be necessary.

The work of the positioning of the pantograph can be reduced almost completely if we renounce the lines drawing as a direct result of the proceeding.

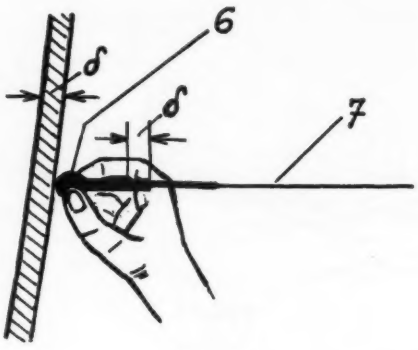

Figure 9.

If we consent to a small amount of intermediate work no reference line will be requested in this proceeding.

The matter stands thus:

The positioning of the pantograph consisted hitherto (Figure 1) in keeping constant the values or l_0, ζ_0, α_0 as well as in keeping the coincidence of the planes (plane of the section and working plane of the pantograph). Refering to Figure 10 we see that the constancy of l_0 and ζ_0 means the constancy of y_0 and z_0. Coincidence of the planes means the constancy of β and γ. Hence of 6 possible freedoms of movement 5 of them (α, β, γ, y and z) had to be controlled and were embraced by the "positioning," while the sixth, i.e., the periodical shifting along the axis x, was loose. This shifting had also to be known, i.e., controlled but that was beyond the task of the positioning. The fulfilment of the conditions of the positioning led to a direct and complete plan of ship's lines (for example body plan) as the result of application of the pantograph.

The bulk of the positioning related to the reference line, hence to the control of the translations y_0 and z_0 (for the rotations, i.e., the angles α, β and γ were easily controllable by precise water levels fixed on the pantograph).

But what will be obtained if we renounce the

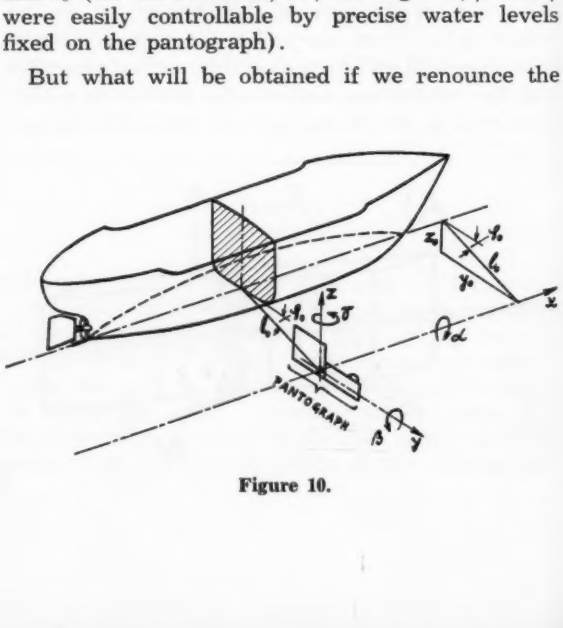

Figure 10.

control of y and z (y_0 and z_0), hence if we renounce the reference line as such and if we retain only the control of constancy of the angles α, β and γ?

It is hardly necessary to say that in this case, too, all the graphs on the pantograph table will be drawn again in the same scale (reduction ratio has remained unchanged). The looseness of y and z will entail only some irregular translations of the graphs towards each other. Nevertheless, the constancy of angles will make that there will be no rotations of the graphs. Hence the result will be a number of scattered graphs on the table which are shifted only by translations and not by rotations.

Thus it remains to arrange the graphs in the drawing office. If the matter is of cross sections, the graphs of those sections pertaining to the straight portion of the keel (portion which is longer or at least equal to the parallel body) are to be arranged easily: their lowest points relating to the center line of the keel, these graphs have to be translated so that the mentioned points lie in one spot. As to the sections relating to the hull's portion beyond the straight part of the keel it is evident that the form of both stem and sternpost must also be taken down by reason of opening the possibility for arranging the graphs. Hence the whole center line of the ship must be taken down. If this line is drawn and if all the periodical shiftings of the pantograph x_i are also known, the arrangement of the graphs relating to sections beyond the straight portion of the keel offers no difficulty. Namely in this case distances are known of the lowest points of these graphs over the spot representing the straight portion of the keel and that is quite sufficient for the arrangement of individual graphs into a plan.

However, although there is no shortcoming on the part of the pantograph for taking down the center line of the hull, an obstacle is offered by the keel blocks which obviate the accessibility to the center line when doing in its plane. To avoid this obstruction we can take down any of the buttock and bow lines instead of the center line. If we know the distance B of these lines from the center line plane (Figure 11) and if also all the shiftings x_i made by taking down cross sections are known again, then the distances H_i are known of intersection points of the buttock and/or bow lines with cross sections from the horizontal line through the keel and that is quite sufficient for an appropriate arrangement of cross section graphs into a body plan.

Hence on behalf of two minor additional jobs—taking down one of the buttock and bow lines and subsequent arrangement of graphs into a plan—the puzzle of reference line marking and positioning of the pantograph as a whole is reduced to keeping only 3 angles α, β and γ constant and that is all.

It is hardly necessary to say that switching over from reference line variant of the proceeding to no-reference line one calls for no sort of modification to the pantograph itself.

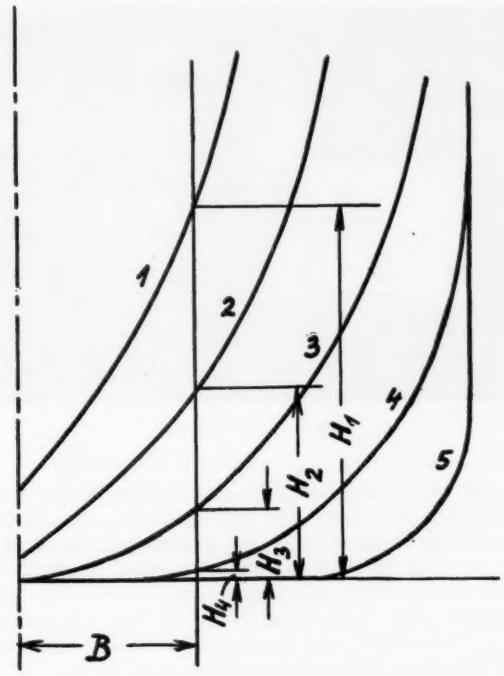

Figure 11.

The efficiency of the pantographic proceeding was substantiated clearly on the occasion of the trial applications of the prototype pantograph in the shipyard of Belgrade. Figures 12 and 13 show the pantograph and the proceeding itself. Full positioning of the pantograph by means of the reference line was used and although the team was inexperienced quite satisfactory body plans have been taken down in only a couple of hours. Somewhat more routine in the proceeding itself as well as some minor artisan improvings of the very pantograph would surely lead to still better results with regard to both speed and precision. Generally speaking the proceeding has proved to be very efficient and reliable.

Before ending it is necessary to mention that not only the forms of the ship's hulls can be taken down by the pantographic proceeding, but also the forms of other voluminous bodies, cavities, etc., can be determined by this proceeding. For example if the section lines of an underground gallery are to be taken down all what was said hitherto stands out also to this case completely. Only the table of the pantograph should be made all around the axis of the rule in order to enable it to operate on all 360 degrees of the circle and in addition to that also some minor modifications to the axle 3 of the pantograph should be made. But if one consents to take down one section in two or more turns and not at one pull this modification turns out to be unnecessary.

Turning again to ships we may remark that there

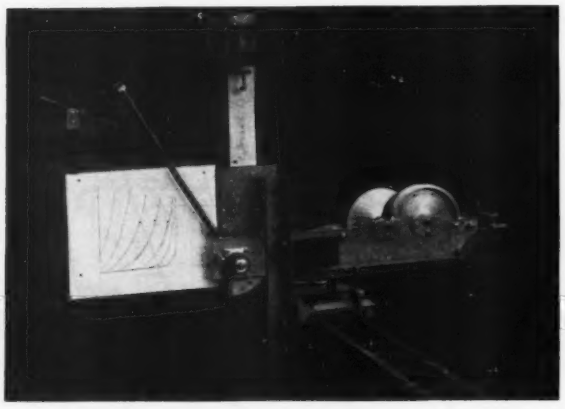

Figure 12. Pantograph.

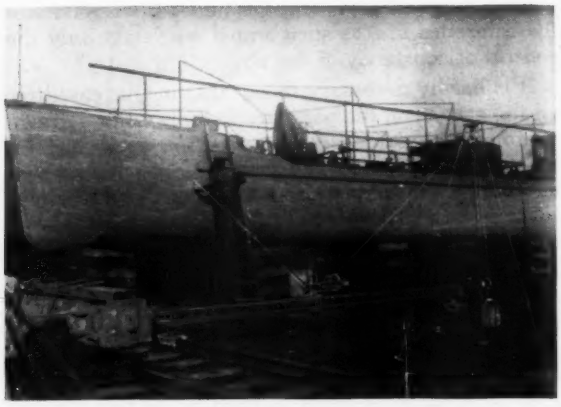

Figure 13. Taking Down the Lines of a Ship's Body Plan.

are specific cases with them where also two or more turns are necessary for taking down one section line. Such is the case of the submarine where it is not possible to reach at once the whole half of the cross section from one positioning point of the pantograph. The measuring cable of the pantograph must be pulled tight freely so that only less than 180 degrees of the quasi-circular cross section of the submarine can be reached from one point. Hence in this case it is necessarily requested to take down lower and upper portions of one-half of the cross section separately from each other and to draw them together only subsequently in the drawing office.

A similar case is met with some river launches, especially with twin screw Kort-nozzle crafts where tunnel-like conduits of water to screws are formed in the stern. In this case the outer portion of the cross section has to be taken down from a "normal" outside point, while the portion pertaining to the tunnel must be treated from a point situated inside the tunnel.

However, the bulk of both sea vessels and river craft relates to the normal case where only one positioning point is necessary for one cross section. Pantographic proceeding can readily be applied to all of them and also to many other non-shipyard cases. Whether the precise positioning of the pantograph, hence the reference line variant of the proceeding, or the no-reference line one is used, good lines drawings can be obtained by this proceeding quickly and reliably. Accordingly it is believed that by the development of the pantographic proceeding a proper contribution is made to the rather neglected problem of taking down the lines drawing from the ship herself.

The National Society of Professional Engineers has recently adopted a definitive policy on the use of engineering titles. This policy is to endorse the use by all employers and classifiers of a standard of qualification for an engineering title in position descriptions. To qualify for the title of engineer under N.S.P.E. standards, a person must fulfill one of the following requirements: he must be registered under a state engineering registration law; he must be a graduate of an accredited engineering curriculum; he must be covered by an official ruling under the Taft-Hartley or the Fair Labor Standards Acts, relative to an engineering position or professional status. Under this policy, persons engaging in engineering work, but not qualified under one of the above requirements, should be classified as engineering aides.

"THE WELDING JOURNAL"

SAFEGUARDS ASPECTS OF REACTOR VESSEL DESIGN

ACKNOWLEDGEMENT

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INTRODUCTION

The discussion presented here deals with the problem of design and the problem of hazards evaluation of vessels for power reactors. Atomic power reactor vessels usually present greater difficulty in design and greater potential hazards than vessels for other types of reactors.

There is a great variety of reactors which can be designed for power production, and there is a wide variation of operating conditions to be met by reactor power systems. However, reactors with large power capacity have certain common characteristics. All contain, during part of their fuel consumption cycle at least, sufficient radioactivity in fission products to present serious hazards if the radioactivity is released. Reactors operating at high rates of heat production per unit mass of fuel are subject to the possibility of release of fission products in case of loss of coolant, either immediately with liquid or slurry fuel-coolant systems or after melting of solid fuel. Loss of coolant may occur through small leaks or as a result of a major rupture.

The quality attained in mechanical design, control of corrosion, materials and fabrication are the major factors in preventing the occurrence of small leaks. The quality of the scientific and engineering effort in design of the power-plant system, components and control and safety system, and the quality of operation and maintenance of the plant will largely determine whether major ruptures will occur.

While the discussion here is directed primarily at design of reactor pressure vessels, much of the discussion is pertinent to other components of the primary coolant system.

THE INDUSTRIAL BACKGROUND FOR DESIGN

One responsible for establishing a code for design and fabrication of a reactor pressure vessel must decide whether an existing design and fabrication code will be satisfactory. If no existing code is considered adequate, he must establish one which makes a satisfactory compromise among numerous factors. At the outset he should recognize that absolute reliability cannot be achieved, and that existing codes meet specific objectives for specific types of apparatus by employing design and fabrication practices based on experience. Inherent in existing codes is recognition of the critical factors in design of a particular type of apparatus and cognizance of the hazards and costs of mechanical failure. It therefore is in order here to examine the development of atomic-power systems in the light of industrial experience.

The development of power reactors presents a situation which is unusual in the evolution of power apparatus. This new source of power is being brought quickly from birth to maturity instead of slowly by an evolution beginning with small, low-capacity, low-efficiency, relatively low-cost units that have been built in the initial stages of development of earlier power sources. Consequently, an unusual emphasis must be placed on engineering and scientific fundamentals in design to substitute for experience which has been gained at moderate cost during evolution of earlier power sources. Because of the huge investments characteristic of power reactors, and their unusual hazards, experience through trial-and-error methods would be prohibitively expensive. With the years required for de-

sign, construction and proof of reliability of a power reactor, progress would be seriously delayed if trial-and-error methods were employed without success.

Perhaps the single factor which has contributed most to the industrial technology and high standard of living enjoyed by most of the world today is the availability of structural materials which have a large capacity for absorbing punishment. If all metals were brittle, apparatus would be much more cumbersome, and far more comprehensive design engineering would be required to assure reliability. With the ductile materials available to us it is often possible to employ simple design rules or trial-and-error methods.

As the technology of mechanical design has progressed we have learned more and more about the capacity of structural materials to absorb punishment. Much is now known about static yielding and fracture phenomena under complex states of stress. Much is also now known about the resistance of metals to cycling of stresses for millions of cycles. Reliable design practices and codes have been established for static or infrequently cycled loads and for millions of cycles of constant intensity. Much attention is currently being given to the intermediate range where design for static loading is not adequate, but where it is not practicable to limit local stresses to the endurance limit. It may be safe to design some atomic-power plants on a static-load basis; however, depending upon the characteristics of the plant or its application, cycling of pressures and temperatures may place the design in the intermediate range with respect to fatigue.

One of the most important problems in a new engineering development is the recognition and evaluation of the new problems which arise or the new significance of old problems which have been encountered in industry. Some of the new problems are recognized readily because of their close association with the fission process. Most likely to be neglected are old problems about which engineers have become complacent, because they have not required comprehensive treatment in design of conventional apparatus. Thermal stresses lie in the latter category. Only recently have there been comprehensive studies of the ability of metals to withstand cycling of thermal strains.[1]

If the economic and technical aspects of design could be evaluated precisely, the greatest profit and industrial progress would be made by the manufacturer making an optimum compromise between the costs of design, materials and fabrication on the one hand and the performance of his product on the other hand. For the purposes of the present discussion we neglect here the cost of marketing the product and other nontechnical factors. Precision in economics and engineering is not generally attainable. However, industry does attempt to achieve a proper balance between the opposing factors. It is for this reason that all engineering aspects of industrial apparatus are not routinely given comprehensive treatment. Industrial practices have been established to give adequate quality of design and manufacture in those areas where judgment and experience show the need for close control of quality. Development of an entirely new source of power warrants close examination of established practice to determine its suitability to cope with the new problems which arise.

Some design practices are established to protect the public interest from the standpoint of safety. The Boiler and Pressure Vessel Code of the American Society of Mechanical Engineers is an example of this type of Code. It prescribes rules for design, fabrication and inspection with the objective of assuring safety against explosion hazards. Adherence to the Code does not assure long-term reliability of a pressure vessel for all types of service. The limited scope of the Code is illustrated by the following excerpt from page 99 of Section VIII (1956) of the Code, which is applicable to unfired pressure vessels:

". . . it is a basic principle that the Code rules are intended to provide minimum safety requirements for new construction, not to cover deterioration which may occur in service as a result of corrosion, instability of the material or unusual operating conditions such as fatigue or shock loading."

In connection with the exclusion of consideration of fatigue damage it is noteworthy that Section VIII of the ASME Code prescribes for thermal stresses a limit only on the membrane component in combination with effects of other loads. (See paragraph UG-23 (b) of Section VIII of the ASME Code, 1956.)

There is a continual advancement in industrial design practices and design codes paralleling advancements in engineering technology. These advances have permitted growth in the performance achieved by industrial apparatus. Contributing factors have been improved materials, more knowledge of their mechanical behavior, improved control of quality of materials and lower and more rationally established safety factors. A major contribution to these advances is the work of the British Welding Research Association and the Pressure Vessel Research Committee of the Welding Research Council.

It is of particular interest in noting progress in the field of power-apparatus design that the 1955 edition of the American Standard Code for Pressure Piping[2] now employs a much more rational basis for limitation of thermal-expansion stress than was formerly employed. The following quotation of paragraph 620 (h) of the previous edition[3] shows the need for improved fatigue criteria.

"Where a piping system is subject to temperature changes of a definitely cyclic nature or to severe vibration that may result in failure by fatigue, the

limit of the safe combined stress permitted in paragraph (g) shall be divided by 2."

The new edition places limits on the range of thermal-expansion stress which depend on the number of cycles of temperature variation expected. The highest allowable-stress range is applicable to systems which are designed for 7000 cycles or less. Allowable-stress reduction factors are specified for more frequent cycling.

Now let us summarize some of the new factors which must be taken into account in establishing practices for evaluation of reactor-pressure-vessel design problems, and for control of stress levels and quality of material and fabrication.

1. Reliability has a higher value in the first unit of a prototype of a basically new type of power plant, because its operation provides a check on quality of design and fabrication. A gamble which failed to pay off in a prototype would call for further time-consuming development with consequent delay in utilization of atomic energy.

2. The difficulty of decontamination and repair or replacement of a reactor pressure vessel might inactivate a huge investment for a much longer time than would repair or replacement in a conventional power system.

3. The potential hazards to operating personnel, the public and property are much greater than with conventional power plants.

4. Radiation damage to structural materials may impair their mechanical properties.

5. Dissociation of coolants (water in particular) may aggravate corrosion and hydrogen embrittlement problems.

6. Unusually-severe thermal transients can occur, particularly due to emergency shutdown, in reactor systems employing a large temperature rise of coolant through the reactor. A large temperature rise is usually used when liquid metals or gases are employed as coolants.

7. Thermal stresses during normal startup and shutdown often require particular attention, because the vessel configurations employed often have regions of slow thermal response in complex structures and have stringent requirements on dimensional stability.

8. Internal heat generation in the pressure-vessel wall is a new problem. It may produce high thermal stresses which will be particularly significant in systems subject to frequent cycling of load. This problem is of most concern in heavy walls of vessels for gas- or water-cooled reactors.

In view of the above new considerations, it appears essential that a comprehensive basis for control of stresses, corrosion and quality of materials and fabrication be employed. The increased investment in engineering, materials, fabrication and inspection will undoubtedly be repaid in full measure by the increased safety and reliability which will be attained. While no industrial pressure-vessel code is sufficiently comprehensive to cover all aspects of reactor pressure-vessel design and fabrication, it is to be expected that suitable codes will be established in the future.

COMPREHENSIVE STRUCTURAL-DESIGN BASIS PROPOSALS

In the past several years there have been substantial efforts towards the development of more rational and exacting structural-design bases, particularly for vessels to be used in critical service. Recent papers by Murphy, Soderberg, and Rossheim[4] review pressure-vessel design practices and problems and indicate tentative basic principles for revision of the ASME pressure-vessel codes. Three classes of vessels are proposed. One of them is the "critical class." This class might be applied to reactor pressure vessels by virtue of their radioactivity hazards. The proposals of these authors include recognition of the different significances of steady-state and cyclic loadings and of membrane and local stresses.

Of particular significance to reactor-vessel design is the joint effort of the United States Navy Bureau of Ships, the Bettis Atomic Power Department (Westinghouse Electric Corp.), and the Knolls Atomic Power Laboratory (General Electric Co.) to develop a structural-design basis for naval reactor pressure vessels. A draft of this basis was originally circulated for comments in 1955 and is essentially summarized in Reference 5. A second, and substantially revised, draft was circulated in early 1957. A similar basis is now in use for certain naval reactor designs, and it is anticipated that formal adoption is forthcoming. This design basis is similar in many gross respects to the proposals of Reference 4, differing in details and in handling superposition of cyclic loadings of various intensities and occurrence frequencies.

PROBLEMS IN DESIGN EVALUATION

In development of a new type of atomic power plant, component and system design and evaluation will proceed in parallel, since they are interrelated. This requires that good judgment and sufficient conservatism be used in prediction of system-operating transients for design of components. Thereafter the component designer must recognize all significant sources of stress and make an adequate evaluation of them. Some pertinent examples of structural analysis have been discussed by Horvay.[6]

Design of reactor power plant components often requires unusual care in calculation of temperature distributions because of the common occurrence of high steady-state or transient thermal stresses. Rapid thermal transients are inherent in reactor-protective (scram) systems, and reactor-control systems may readily be designed for rapid maneuvering of power. The effects of thermal-driving heads and vapor for-

mation may be important in modifying temperature distributions in reactors and heat exchangers, particularly under low-flow conditions. An interesting and sometimes troublesome characteristic of reactors is the redistribution of heat production which occurs after a power transient due to delayed heating from fission products.

In seeking compliance with a design basis requiring limitation of local stresses to definite values, the pressure-vessel designer soon is hampered by the fact that many common problems have not yet been solved. A sound fundamental understanding of elasticity and good judgment is required to assure that stresses are not seriously underestimated. In many cases it will be necessary to do original theoretical or experimental work to evaluate problems.

LOADINGS WHICH CONTRIBUTE TO POTENTIAL HAZARDS

Any loading which may result in leakage from the vessel is a potential source of hazard. The more significant of these are: (a) coolant pressure, (b) cyclic operation, (c) earthquake (or shock loading in a mobile plant), (d) nuclear accident, and (e) chemical accident.

The first three of these loadings are those with which the designers of power plants are familiar, so they will not be discussed in detail here.

The possible causes of nuclear and chemical accidents and means for their prevention are beyond the scope of this paper. However, certain characteristics of these accidents are pertinent and will be discussed.

A very important point to be understood with regard to the dynamic aspects of the loadings which result from either a nuclear or chemical accident in a reactor is that the explosions which can be postulated reasonably have inherently more than an order of magnitude longer energy-release duration than conventional fast-reacting explosions. The detonation-wave velocities in large explosive charges are in the range of 14,800 to 28,000 ft/sec.[7] The duration of release of about 10^8 calories of energy from a centrally detonated 2-ft diam spherical charge (about 440 lb) of TNT would be on the order of 50 microseconds. The load application on the vessel would be abrupt with a pressure-rise time much smaller than 50 microseconds.

The value of 10^8 calories is a reasonable estimate of the nuclear-energy release attainable in the worst-possible accident in a compact reactor with highly enriched fuel. However, the nuclear excursion periods which can be attained are usually considered to be one or more orders of magnitude longer than 50 microseconds, being limited by the lack of means for producing large and rapid surges in reactivity. Consequently, the loading on the vessel will increase during the period of energy release, and shock-wave effects will be relatively unimportant.

In the case of a chemical reaction between uranium metal or fuel-element cladding and water, maintenance of the reaction requires mixing of the reactants by diffusion and other means, and the reaction would not be simultaneously initiated throughout the reactor core. Hence, such a reaction is evidently much slower than an equivalent energy release from a detonating explosive.

From the above discussion it should be evident that caution is in order in relating reactor-safeguards evaluations to "equivalent" detonations of chemical explosives. In particular, shock-wave effects will be much less significant in reactor accidents than in detonating explosions. The assumption of a detonation of the same energy release may lead to a faulty indication of the effects of the explosion and the protective measures which should be used.

Even though a reactor accident is much slower than a detonating explosion, the peak pressure developed in the pressure vessel may be developed in a time comparable with the radially-symmetric natural period of the vessel. In the elastic case this can lead to a transient doubling of deformation relative to that which would be produced statically by the same pressure. In a ductile vessel a suddenly applied pressure corresponding to a hoop stress equal to the yield strength under static loading would normally cause a small amount of plastic flow without risk of rupture. Under more intense loading, analysis of the effects of the pressure rise requires consideration of inertia effects and structural resistance to deformation in various directions and the effects of expansion on the reduction of pressure in the vessel. An example of techniques used in reactor-explosion analysis has been presented by Levedahl and Howerton.[8]

DUCTILE FRACTURE OF PRESSURE VESSELS

It is appropriate to recognize that the pressure vessel itself may be the source of a hazard. Rupture of the vessel may occur at one extreme as a small leak due to local fatigue failure with consequent escape of small quantities of radioactive coolant and no other consequences other than a long outage of the system and an expensive repair job. At the other extreme a fatigue crack may propagate slowly without leakage until it is suddenly propagated rapidly under the action of pressure loading, and gross rupture occurs. The consequences in the latter case can be melting of fuel elements and dispersal of fission-product activity as well as coolant radioactivity. The occurrence of local leakage appears much more probable than abrupt rupture, if proper materials, design and fabrication are used. The probability of any failure of the vessel can be reduced by care in design in regions of stress concentration. The careful design of penetrations of the vessel is particularly important. Smooth contours and a gradual transition in thickness in pipe nozzles are very desirable.

A well-designed and fabricated steel pressure

vessel can be expected to have a substantial capacity for withstanding pressures beyond the design value without gross plastic deformation or failure, except for ferritic steels at low temperatures. Meeting the ASME Boiler and Pressure Vessel Code hydrostatic-test requirement essentially assures initial ability to withstand a 50% overload pressure at design temperature without gross membrane yielding or fracture. If the vessel has not been subjected to significant fatigue, corrosion or embrittlement damage, it would be expected to maintain this resistance to pressure. The vessel also would be expected to be capable of withstanding overloads considerably above 150% of the design value with design in accordance with the ASME Code, and it would be expected that a substantial increase of volume could be attained without rupture, if there had been no impairment of mechanical properties of the steel.

An analysis of the extent of uniform plastic strain to be expected in deformation of either a cylindrical or spherical shell subjected to internal pressure is presented in Reference 9. The reference presents a discussion of the yield pressure, maximum pressure, strain at maximum pressure and the localization of deformation prior to rupture in terms of the initial dimensions of thin-walled vessels and the material properties of vessels made of ductile materials. In addition, design with brittle materials is discussed briefly and the influence of strain concentrations upon differentiation between brittle and ductile materials is discussed. The authors believe the theoretical results of the above paper to be a valid indication that, under favorable conditions, a pressure vessel is capable of a considerable amount of deformation before fracture.

BRITTLE FRACTURE OF PRESSURE VESSELS

The choice of material and the operating temperature may have a substantial bearing on the possibility of catastrophic fracture of the pressure vessel. There is an inherent advantage in austenitic stainless steels over ferritic steels, because in the annealed state they do not exhibit a low-temperature transition from ductile to brittle fracture. They also have a low notch sensitivity, presumably because of the local strain hardening which resists crack propagation.

The brittle-fracture characteristics of ferritic steels have been described by Pellini[10] in terms of a quantity designated as the "nil-ductility transition temperature (NDT)." It has been found that this temperature correlates fairly well with the temperature at the 20 ft-lb level of the Charpy V-notch impact test for carbon and very-low-alloy steels (such as ASTM A212) and with the 30 ft-lb level for more-highly-alloyed steels (such as ASTM A302). For a vessel as critical as a reactor vessel, it is the present authors' opinion that full operational pressure should not be applied at a temperature less than NDT + 30°F, and that the hydrostatic-pressure test (at 150% of maximum allowable working pressure) should not be applied at temperatures less than NDT + 60°F in vessels designed in accordance with Reference 5. Higher minimum temperatures are probably in order for vessels designed and fabricated to current industrial codes. Some decrease of these temperature margins is probably in order in the case of large forgings for which a significant number of specimens have been tested at critical locations.

There may be a significant risk of development of undetected internal cracks in a ferritic steel during hydrostatic testing at insufficiently-high temperature. Conditions may be conducive to development of a crack initiated at a minor internal defect, but they may not be conducive to propagation of the crack during hydrostatic test. Such a crack might be a source of concentration of cyclic stresses and premature fatigue failure.

With respect to the effects of fatigue damage in reducing deformation capacity, Coffin[1] has shown that plastic-strain cycling to a substantial fraction of the fatigue life makes a substantial reduction in the true stress and strain to fracture in a subsequent uniaxial tensile test. The reduction may be more significant under biaxial loading. If design is conservative with respect to fatigue, this factor will probably not be important. Its importance is likely to be reduced further by virtue of the fact that the regions of maximum fatigue damage are likely to involve local bending stresses. These regions are unlikely to be the regions of maximum membrane strain and consequently may not cause a substantial reduction in membrane strain to fracture. However, this factor contributes to the importance of conservatism in design with respect to fatigue.

A question which deserves investigation is whether fast-neutron irradiation raises the nil-ductility fracture transition temperature. It is expected that the temperature of the irradiation exposure will be an important variable in such an investigation. Some data with regard to this matter have been presented by Baldwin.[11]

MISSILE EFFECTS

If the rate of pressure rise in an accident is sufficient to cause strains to the point of local fracture in a time short as compared with that for propagation of stress-relief waves around the half-periphery of the shell, fracture will occur in more than one region. If initial fracture of a cylindrical shell occurred along two generators at the ends of a diameter, and if at fracture the two semicylindrical shells had high velocity, the relief of applied pressure would not preclude the occurrence of additional fractures, because the initial velocity of the parts of each semicylindrical shell is radial rather than

unidirectional. Forces must be sustained within the shell sufficient to change the radial velocities to a unidirectional velocity, or additional fracture will occur.

Velocities of large portions of a pressure vessel resulting from violent fracture can be estimated from energy considerations. In cases in which the authors have assisted in hazards evaluation, the velocities corresponding to the worst-possible reactor accidents have been on the order of a few hundred feet per second—about an order of magnitude slower than missiles which are commonly considered, i.e., those from gunfire or detonating explosives. Also, missiles from a reactor incident probably would be larger than those usually of interest in barrier-penetration problems.

The nature of missile damage will depend upon the nature of the barrier which resists missile penetration. The biological shielding may be a barrier sufficient to confine missiles from the reactor pressure vessel, or the shield structure may be incapable of withstanding the pressures existing after rupture of the vessel and may thus be another source of missiles.

The most satisfactory means for providing confinement of radioactivity is probably the use of a steel building designed as a pressure vessel such as has been proposed for a number of power plants now under development. A steel shell of large size can readily be designed to resist the pressure loading resulting from incidents far beyond the containment of a reactor pressure vessel, largely because of the rapid increase in volume with increasing diameter. Hence, while it may be impracticable to design a reactor pressure vessel to confine the worst-conceivable incident, it is practicable to design a steel building to confine such an incident, at least with respect to pressure-resisting capacity. However, one must consider the possibility of local penetration of the building shell by a sharp corner of a fragment of the pressure vessel or a gross rupture due to a fragment passing entirely through the shell. With edge-on incidence, a piece of plate may penetrate the shell by local shearing and tearing. With parallel incidence at moderate velocity, the impact would cause a local bulge and strains distributed over a substantial area of the shell would absorb the kinetic energy of the missile. By moderate velocity here we refer to velocities much lower than the velocity of plastic-stress waves in the steel shell. We also refer in the case of parallel incidence to missiles whose major dimensions are much larger than the thickness of the missile.

The resistance of a steel shell to penetration by edgewise-incident missiles from a violently-fractured pressure vessel can probably be increased considerably by the use of an interior coating of a couple of inches of concrete reinforced with steel mesh. The concrete will offer additional resistance to penetration and will distribute the local loading over larger areas of the steel shell. Alternatively, it may in some cases be preferable to provide missile barriers separated from the containment building itself.

The above discussion of missiles is considered appropriate in view of the common use or proposal of pressure-tight enclosures around reactor power plants. The authors do not mean to imply that such enclosures are without disadvantage. There may be an increased risk of occurrence of a severe accident as a consequence of system complications introduced by use of a pressure-tight enclosure, particularly if the plant is operated by personnel outside the enclosure. If operators work inside the enclosure, there may be increased hazard to the operators in case of some otherwise minor accidents.

The authors urge presentation to the technical societies of papers reporting the diagnosis and effects of explosion accidents. Such data are of considerable value in making a realistic appraisal of the probable consequences of potential power-reactor plant explosions and are helpful in design of protection against missile damage. An interesting summary of boiler and pressure-vessel failures has been presented to the Institution of Mechanical Engineers by Eyers.[12]

CONCLUSION

The authors conclude that a pressure vessel for a power reactor requires a more comprehensive control of design, materials and fabrication than is employed in conventional pressure vessels, which entail lesser hazards, cost and difficulty of repair.

Well designed and fabricated pressure vessels can be expected to have a substantial overload capacity to resist accidental, abnormal pressures and can be expected to deform without rupture sufficiently to enable a substantial core-and-coolant expansion. This deformation affords a means for reducing reactivity and limiting the energy release of a nuclear accident.

It appears practicable to provide a high degree of reliability against rupture or missile penetration in a steel building designed as a pressure vessel for confinement of power-reactor incidents.

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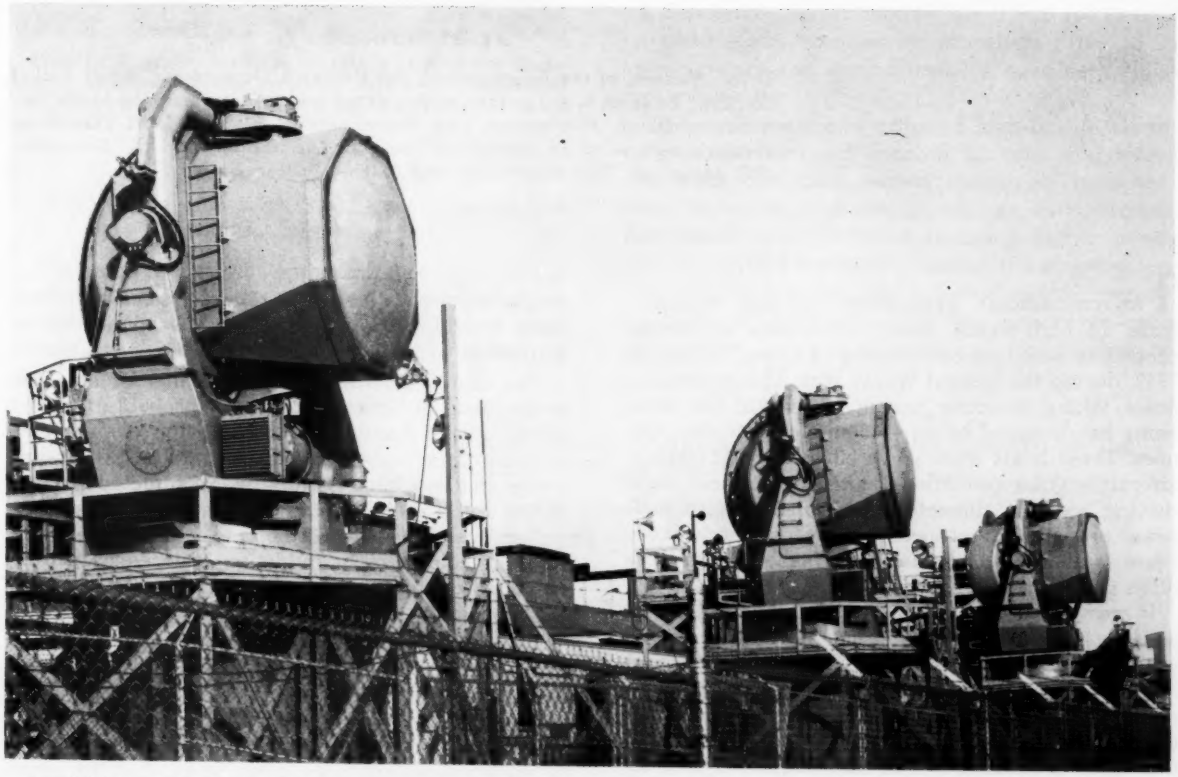

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"THE SHIPBUILDER & MARINE ENGINE-BUILDER"

THE DEVELOPMENT OF HIGH-TENSILE ALUMINUM-BRONZE ALLOYS FOR MARINE PROPELLERS

ACKNOWLEDGEMENT

Mr. F. Hudson, of the Development and Research Department, Mond Nickel Co., Ltd., London, is the author of this paper which was presented to the Institute of Dutch Shipbuilders and Shipowners 22-24 May, 1957. This is an abridged version of an abstract of the paper as published in the December 1957 edition of "The Shipbuilder and Marine Engine-Builder."

THE COMMERCIAL application, on any extensive scale, of high-tensile aluminum-bronze in marine propellers was first commenced in Great Britain in 1942, during the Second World War. Motor torpedo-boats, taking an active part in the war at sea, were being handicapped by an epidemic of propeller failures. These boats were powered by three 2,000-h.p. aircraft engines (modified for marine service), each driving a 30-in. diameter three-blade high-tensile brass propeller at a speed of approximately 2,000 r.p.m., and when a blade came off, the results were often disastrous.

It was found that the fracture of the blades was actually due to corrosion fatigue, and that, in all cases, the cracks had started in tension in the root section of the leading face of the blade. The use of nickel-aluminum bronze was recommended as an alternative, in view of its much higher resistance to this form of failure; it was also suggested that all high-speed propellers should be cast in such a way as to put any minor defects (dross inclusions, etc.) on the trailing face of the blade, *i.e.*, the side under compression.

Following these recommendations, the British Admiralty arranged for a trial of nickel-aluminum bronze to be made and the results were so successful that this alloy was immediately adopted as standard material for propellers in motor torpedo-boats. Many thousands were subsequently made without a single service failure and there is no doubt that these provided the incentive for the application of propellers in this alloy to larger ships.

The first aluminum-bronze propeller of any size to be made in Great Britain was probably that ordered by the Admiralty for H.M. tug *Nimble*. This variable-pitch propeller, approximately 10 ft. in diameter and weighing 6½ tons, was completed in 1946. Some initial difficulties in the casting of these propellers were soon overcome, and it became evident that the commercial production of large propellers in nickel-aluminum bronze was definitely a practical proposition.

Development activities by the principal propeller manufacturers in both Great Britain and the United States now proceeded apace, and, since 1946, several thousand tons of high-tensile aluminum-bronze propellers have been fitted to many types of ships. Some of these propellers have given more than 10 years of trouble-free service and the largest yet to be made in the United Kingdom for a single-screw oil-tank ship is illustrated in Figure 1. This propeller has a finished weight of 30½ tons, and it is interesting to note that if this casting had been made in ordinary high-tensile brass, its weight would need to have been increased to at least 35½ tons. Propellers of similar size have also been successfully produced in the United States.

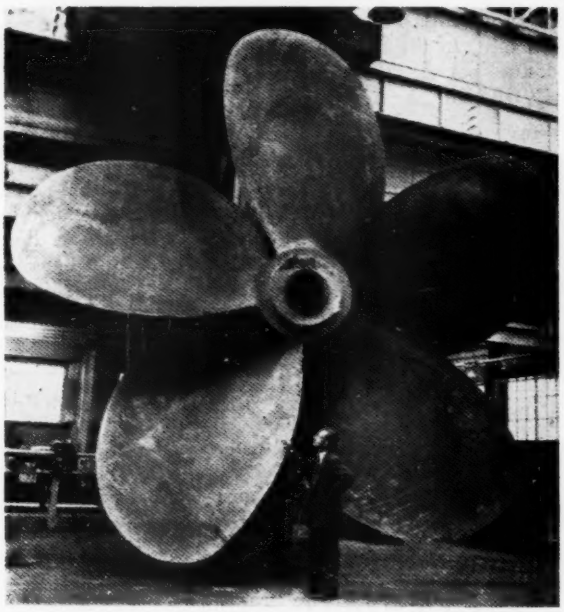

Figure 1. Propeller for large oil-tanker in Novoston High-tensile Aluminum-bronze, weighing 30½ tons, produced in 1956. The total metal required to make this casting amounted to 48 tons.

ADVANTAGES OF HIGH-TENSILE ALUMINUM-BRONZE FOR PROPELLER SERVICE

The composition and properties of high-tensile aluminum-bronze alloys used for the production of marine propellers in the United Kingdom, in comparison with high-tensile brass, are outlined in Table I. It should be noted that the properties given in this table were obtained from separately-cast test-bars.

Test-pieces cut from actual propeller castings indicate that the mechanical properties of high-tensile brass, in sections approximately 7 in. thick, are of the order of 80 per cent of those obtainable from separately-cast bars so far as strength and elongation are concerned.

In the case of nickel-aluminum bronze, the tensile strength, in similar casting sections, was found to be approximately 90 per cent of that obtainable from separately-cast test-bars, while the ductility was practically the same.

The strength of cast high-tensile aluminum-bronze increases at sub-zero temperatures. Investigations conducted by the International Nickel Company, Inc., show that the strength at −50°F is approximately 7 per cent higher than at room temperature, while elongation and impact properties are unaffected. Service tests conducted by the U.S. Navy in 1955 on nickel-aluminum bronze propellers fitted to 25 ships operating in Arctic icefields gave very satisfactory results.

The mechanical properties of high-tensile aluminum-bronze are much superior to those of high-tensile brass, and they remain reasonably consistent even in castings of heavy section. Furthermore, high-tensile aluminum-bronze has a higher resistance to cavitation-erosion, corrosion and corrosion-fatigue in sea-water, and a lower specific gravity. By taking all of these factors into account, co-operative effort between designer and founder has re-

TABLE I—*Properties of High-tensile Aluminum-bronze Alloys used in the United Kingdom for the Production of Marine Propellers*

Test-bars Cast in Sand Molds

Properties	High-tensile Aluminum-bronze		High-tensile Brass
	B.S. 1400-AB2-C Per Cent Al... 9.5 Ni... 4.5 Fe... 4.0 Mn.. 1.5 Cu...Remainder	Novoston Per Cent Mn..12.0 Al... 7.5 Fe... 2.5 Ni... 2.0 Cu...Remainder	B.S. 1400-HTB-C
Proof stress (0.1 per cent), tons per sq. in.	16	18	12
Brinell hardness number	160	160	140
Izod impact, ft. lb.	20	25	15
Limit of proportionality, tons per sq. in.	8	12	6
Modulus of elasticity, millions of lb. per sq. in.	17.5	16.6	14.5
Specific gravity	7.65	7.5	8.32
Corrosion-fatgue in sea-water (50×10^6 reversals), tons per sq. in.	9	9	5

The percentage elongation obtained under the conditions required by various official specifications is not always comparable. For instance, owing to the local "necking" which occurs in the tensile test, the ratio of the gauge length to the cross-sectional area (or the diameter) has an important bearing on the elongation expressed as a percentage, and it is obvious that the bigger the ratio, the smaller will be the percentage elongation.

sulted in the development of a better, and lighter, marine propeller.

The principal advantages of aluminum-bronze over high-tensile brass for marine propellers are related to the following considerations: (1) Working stresses, (2) weight, (3) moment of inertia, (4) efficiency, and (5) maintenance costs.

Working Stresses

By virtue of the difference in properties, it is possible to use, for an average propeller operating under normal conditions, a design stress of 6,500 lb. per sq. in. for nickel-aluminum bronze, as compared with 5,750 lb. per sq. in. for high-tensile brass. This has the effect of reducing the blade-section thickness, with a consequent improvement in efficiency and a reduction in propeller weight.

Weight

Due to differences in density, a high-tensile brass propeller weighing, say, 15 tons, if made from the same pattern, would weigh only 13.8 tons in nickel-aluminum bronze. By making use of the increased permissible stress, the weight of the aluminum-bronze propeller can be still further reduced down to approximately 13 tons.

This is a decided advantage in favor of nickel-aluminum bronze, particularly at the moment when propeller weights are continually increasing. The development of the large single-screw tanker, for example, may soon be restricted because of the fact that an ordinary high-tensile brass propeller would be too heavy to be readily handled in the ship. Conversely, the use of an aluminum-bronze propeller would enable the size of the ship to be increased for a given maximum propeller weight.

The reduced propeller weight has other advantages in connection with shafting stresses, less wear on shaft bearings, less power required, etc.

Moment of Inertia

In designing new ships, it is now the practice to investigate carefully the torsional vibration characteristics of the shafting system; in this connection, it is frequently necessary to impose a limit on the moment of inertia of the propeller. If high-tensile brass is used, the only way to limit the moment of inertia is to limit the propeller diameter, with a consequent reduction in efficiency. A nickel-aluminum bronze propeller is generally about 15 per cent less in moment of inertia, so a larger propeller can be fitted, and may give an increase of efficiency of perhaps as much as 5 per cent.

Efficiency

Calculations indicate that an aluminum-bronze propeller, having blade thicknesses about 8 per cent less than high-tensile brass, can be 1.5 per cent more efficient. In the case of a ship burning 50 to 60 tons of fuel per day this could mean a financial saving of £7 10s. 0d. per day at present prices.

Maintenance Costs

The mechanical damage sustained by nickel-aluminum bronze as a result of a given blow has been found to be less than that for high-tensile brass. When an aluminum-bronze propeller is damaged, it can be easily repaired by welding. Furthermore, the greater resistance of nickel-aluminum bronze to corrosion and erosion means lower maintenance costs.

The superiority of high-tensile aluminum-bronze as a propeller material has been confirmed by recent tests conducted in the United States on a twin-screw 6,000-ton ore-carrier. These ships subject their propellers to unusually severe conditions by operating over and through sand-bars in the Orinoco River, off the Venezuelan coast. Under such conditions, conventional high-tensile brass propellers had to be replaced, or reconditioned, at fairly frequent intervals. To determine the comparative qualities of the two alloys, under practically identical service conditions, a nickel-aluminum bronze propeller was installed on the vessel's starboard shaft and a high-tensile brass propeller on the port shaft. The propellers were inspected six months after installation and the aluminum-bronze propeller was found to be in excellent condition, showing nothing more than a very light uniform sand-washing effect over the entire surface. The high-tensile brass propeller, on the other hand, was much more heavily eroded and had suffered mechanical damage, giving rise to bent tips, which, subsequently, had to be straightened.

Repair of Damaged Propellers

Bent nickel-aluminum bronze propeller blades can be readily straightened at temperatures in the range of 650° to 850°C providing no actual cracks, or fractures, are present in the metal.

When mechanical damage is sufficient to cause cracking, or fracture, then the affected area of the blade must be cut away and, if necessary, a new section cast, which is subsequently welded into position. The practice of "burning-on," as employed for the repair of high-tensile brass propellers, is not recommended for high-tensile aluminum-bronze.

Two methods of welding are used for the repair of aluminum-bronze propellers, *viz.*, metallic-arc, which employs covered electrodes, and the more recently introduced inert-gas metallic-arc process, which uses a bare filler wire. The presence of impurities in the base material may affect the welding response to either process. Lead and bismuth, in particular, must be avoided.

Metallic-arc Welding

Attempts to develop electrodes to give a matching weld metal of the nickel-aluminum bronze composition have not yet been entirely successful, and straight aluminum-bronze electrodes are generally used, such as the Asea Tenal White Tip. However, recent development work in Great Britain has shown that the Stone Superston 40 composition will provide a core wire for electrodes which have good welding attributes and give better properties than the normal aluminum-bronze electrodes. The coatings for such electrodes all tend to be hygroscopic and it is important that the electrodes are dried immediately before use, in order to ensure a sound deposit.

The metallic-arc process is versatile enough to cope with the welding of large or small areas, but it is usually practiced only in the down-hand, or flat, position. On heavy sections, some preheating to about 150°C is advisable before welding is commenced. Where a considerable amount of weld metal has to be deposited, the sequence of welding may need to be "staggered," to minimize distortion and the risk of cracking.

Some results obtained on butt welds joining 3 in. by 3 in. by ⅜ in. cast plates are given in Table II. The mechanical properties recorded were determined by means of tensometer tests. Both the tensile and the bend tests failed in the heat-affected zone of the base material; this zone varied in width between 0.04 in. and 0.12 in.

Inert-gas Metallic-arc Process

This process is used under a variety of proprietary names, such as Aircomatic, Argonaut or Sigma, and employs bare filler wire fed continuously through a special welding gun, with the arc protected by an argon atmosphere. This process may be used for positional welding and is at its best when considerable quantities of weld metal have to be deposited. The method has the further advantage that preheating of the base metal is not normally required.

The inert-gas metallic process has been adopted very successfully in the United States for the welding of marine propellers. Stranded filler wires have been used comprising copper, aluminum and iron strands, designed to give a deposit containing nominally 9 per cent aluminum and 1 per cent iron. Welded joints made in this way have given a tensile strength of about 40 tons with some 15 per cent elongation, and failure occurred in the weld metal itself or in the heat-affected zone of the base material. In bend tests on such joints, an angle of about 45 deg. has been achieved.

In the U.S.A., experimental work on the use of nickel-aluminum bronze filler wires has revealed a tendency for the weld deposit to crack during deposition. It seems possible, however, that this cracking tendency may eventually be overcome by reducing the aluminum content of the filler wire, or by introducing a little oxygen in the argon stream during the welding operation. Meanwhile, in Great Britain, experiments made with a Superston 40 type of wire, as an alternative to the straight aluminum-bronze, have shown considerable promise.

CASTING OF MARINE PROPELLERS

Most of the high-tensile aluminum-bronze propellers produced in the United States of America and Great Britain during the past 10 years have been marketed under such trade names as Nialite (Baldwin-Lima-Hamilton Corporation) and Nikalium (Manganese Bronze & Brass Company), and have been made in alloys similar to that covered by British Standard Specification 1400-AB2-C.

TABLE II—*Mechanical Properties of Metallic-arc Welds Joining Nickel-aluminum Bronze Plate Castings*

Test Sample	Composition, Per Cent	Max. Stress, Tons per Sq. In.	Elongation, Per Cent	Hardness D.P.N. (Average)	Bend Test, Degrees
Cast Plate	Aluminum.....9.39 Iron.....4.32 Nickel.....3.64 Manganese.....1.10 Copper..Remainder	35.4 47.3 45.7	28.0 34.0 25.0	 157	39 63 58
Weld	Aluminum.....9.0 Iron.....2.0 Nickel.....Nil Manganese.....1.0 Copper..Remainder	49.7 39.2	18.0 13.0	 160	 40

The bend-test specimen was 1 in. wide, ⅜ in. thick, bent round a 1-in. dia. former.

Recently, however, a new patented alloy has been developed in Great Britain for marine propeller service under the name of Novoston (Messrs. J. Stone & Company). This material differs from the conventional high-tensile aluminum-bronzes inasmuch as it contains 10 to 15 per cent manganese and has higher proof stress and toughness combined with improved castability. This latter property is extremely important in the production of large castings and some measure of the improvement which has been effected can be obtained from the fluidity tests shown in Figure 2.

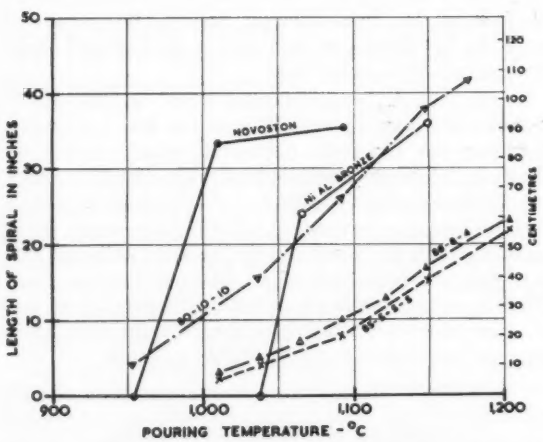

Figure 2. Fluidity of High-tensile Aluminum-bronze in comparison with gunmetal.

Melting Practice

The aluminum-bronzes are susceptible to hydrogen-gas unsoundness but not to reaction-gas unsoundness. The presence of aluminum reduces the oxygen solubility to a very low value, so that oxidation treatment cannot be employed to eliminate dissolved hydrogen. Scavenging treatment with nitrogen ensures thorough degassing. In practice, degassing treatment is rarely found necessary for small melts, which can be melted quickly in crucibles, but may be required when large quantities of metal are slowly melted in open-flame reverberatory furnaces. An important point in melting practice is to avoid excessive agitation by stirring, as the oxide film on the surface of the metal affords protection from hydrogen absorption. In all cases, rapid melting under slightly oxidizing conditions gives the best results.

Deoxidants used in the manufacture of aluminum-bronze vary widely. Most deoxidant additions are made in the belief that they will act with any oxides present in the melt, but, in actual practice, there are few deoxidants capable of reducing aluminum oxide. The use of silicon for deoxidation purposes, though countenanced by some casters, is condemned by the majority on the grounds that impact strength and ductility may be adversely affected. Manganese is possibly the most widely used deoxidant for aluminum-bronze, although, in this respect, manganese cannot be considered as a particularly active element. Magnesium is sometimes used in small quantities (say, of the order of 0.02 per cent), in addition to manganese, as it is capable of reducing Al_2O_3. The analysis of another deoxidant found successful in the large-scale production of aluminum-bronze is given in Table III.

TABLE III

	Per Cent
Aluminum	37.0
Manganese	6.0
Magnesium	2.0
Calcium	1.0
Titanium	0.6
Copper	Remainder

This alloy is added, in amounts of 0.5 to 1.0 per cent, to the molten metal about 5 min. before pouring.

To obtain satisfactory mechanical properties, the composition must be maintained within close limits and the furnace charge must be made up from ingots of known composition, plus foundry scrap from previous melts. Aluminum content is particularly critical, and is impossible to control exactly if the furnace charge is composed of virgin metals. It should also be noted that the properties of high-tensile aluminum-bronze are seriously affected by the presence of impurities. Little information is as yet available on this subject, but it is desirable that the more common elements should be kept to the limits given in Table IV.

TABLE IV

	Per Cent Not More Than
Lead	0.05
Tin	0.10
Silicon	0.25
Magnesium	0.05

A suitable base composition would consist of 9.5 per cent aluminum, 4.0 per cent nickel, 4.0 per cent iron, 1.5 per cent manganese and the balance copper.

The melting of large heats is invariably conducted in oil-fired reverberatory furnaces. Melting should be conducted as rapidly as possible and, as a guide in this direction, the melting times outlined below have been found to give satisfactory results.

15-ton Furnaces.—1¾ to 2¼ tons per hour, using 8 to 10 per cent by weight of fuel oil, to weight of charge melted.

30-ton Furnaces.—2 to 2½ tons per hour, using 6 to 8 per cent by weight of fuel oil to weight of charge melted.

After the metal has been melted and superheated, and just before it is tapped from the furnace, a test is made for gas content using the reduced-pressure test as developed by the British Non-ferrous Metals Research Association for aluminum-base alloys. The result of this test determines whether or not nitrogen degassing is required.

Following the test for gas content, a check is made on the aluminum content. A close estimation of this element can be obtained from the appearance of the microstructure shown by a standard test coupon. The method employed is to make a sand mold (normally in core sand, so that a stock of molds can be maintained) with an open top to provide a bar 3 in. by 1 in. by 1 in. A spoon sample of the molten metal in the furnace is poured into the mold and allowed to stand for 15 min. The bar is then knocked out and quenched. A small specimen is cut from the bar, quickly polished and etched, and the proportion of alpha to beta constituents estimated by comparison with standard photo-micrographs.

Molding Methods

In the casting of aluminum-bronze propellers there are two rules which must always be remembered. The first is to ensure that the leading faces of the blades are always cast down, and the second is that the metal is poured with the minimum of turbulence, and at the lowest possible temperature consistent with a completely run mold.

Small propellers are best made in dry sand, or in molds made from silica or carborundum sand using the CO_2 process. Use of the latter sand is particularly advantageous if a high level of mechanical properties is required in the final casting.

In Great Britain, the molds employed for large propellers are invariably made in cement-bonded sand and they are run from the bottom of the central boss. Feeding is accomplished by means of a head on top of the boss, and in recent years the size of this head has been markedly reduced by the use of exothermic sleeves and feeding compounds. A detailed and up-to-date description of the methods used for the production of large marine propellers has been recently published by Langham.* On reference to this paper, it will be observed that one downgate (3½ in. bore for 20-ton cast) is employed for castings weighing up to 25 tons. For larger castings, the mold is poured from two ladles into two similar, but independent, runner systems entering at opposite sides of the boss. Figure 3 shows that, to avoid metal turbulence at the junction of the bottom of the downgate with the ingate, the use of a curved pipe is suggested. The ingate is usually of either circular or flat rectangular section, and has a flared-tangential entry into a combined dirt-trap and choke-chamber situated underneath the central boss of the propeller. From the choke-chamber, the metal enters the boss by means of a thin cylindrical skirt or flash-runner. With this method of running, the

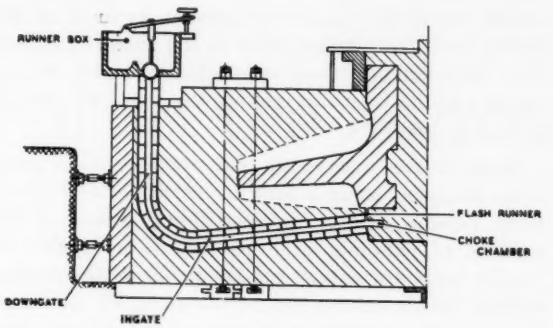

Figure 3. Method of running large propellers (Langham).

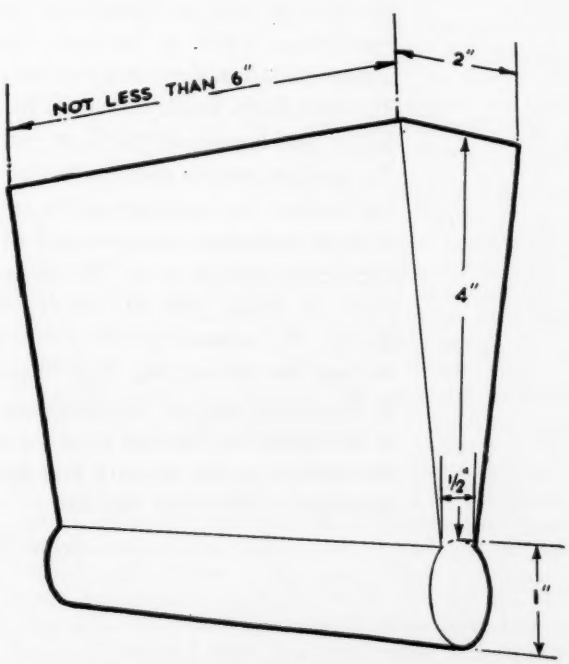

Figure 4. Recommended method of making separately cast test-bars for use with nickel-aluminum bronze. The bars can be cast from the top, using Durville pouring methods or from the bottom, by means of a small ingate attached to one end of the test-bar.

* "Founding the Marine Propellers" (Proc. Inst. of British Foundrymen, 1954; Vol. 47, pp. B. 126-B. 142).

metal enters the boss very quietly, as most of the initial turbulence takes place in the choke-chamber. This chamber is formed by simply sweeping an extension to the boss and making the required modifications to the core.

Experiments conducted with model molds made from perspex, using a mixture of water and aluminum powder as the liquid medium, show that this method of running large propellers is capable of giving excellent results so far as the ideal pattern of flow for aluminum-bronze is concerned. In actual practice, the number and area of the ingates employed will be primarily determined by the size of casting being made; and as a guide in this direction, each ingate should be capable of delivering approximately 2½ to 4 tons of molten metal per minute.

Suitable pouring temperatures for high-tensile aluminum-bronze conforming to B.S. 1400-AB2-C may vary from 1,100 to 1,150°C, according to the size of propeller being produced.

Test-Bars

The function of a test-bar is to provide an indication of the quality of the metal from which it is cast and it is considered that this can most readily be obtained by the use of the standard form of separately cast test-bar illustrated in Fig. 4.

Test-bars should not be attached to the propeller casting, as the correct pouring temperature for test-bars may not necessarily be the same as for the different conditions in the casting itself. Wilson and Tull* have published the results of an investigation into the effect of casting temperature upon the properties of test-bars. It was found that the best mechanical properies are obtained from high-tensile aluminum-bronze B.S. 1400-AB2-C test-bars when these are cast at 1,125°C. Lower pouring temperatures, such as may be satisfactorily employed for large castings of heavier section, are unsuitable for test-bars. Furthermore, when test-bars are attached to castings, they invariably tend to collect dross.

* "Observations on the Melting and Casting of Aluminum-bronze Alloys, with special reference to Test-bars." (*The British Foundryman*, 1957; Vol. 50, pp. 237-245.)

The Sodium Reactor Experiment (SRE) was formally placed in operation in November, 1957, at its Santa Susanna Mountains site in California. A cylindrical core, six feet by six feet in diameter is the heart of the system. The core heats liquid sodium in the main loop, which enters the reactor at 500°F and leaves at 960°F. A sodium flow of 485,000 lb/hr is designed. The sodium loop is constructed of stainless steel and equipped with electric heaters for maintaining the sodium in a liquid state during shut-down. A heat exchanger, constructed of stainless teel, transfers energy to the secondary sodium loop. This heat exchanger has a heat transfer coefficient of about 985 BTU/hr-ft²-°F and a designed flow velocity of 4 ft/sec. The secondary sodium is heated from 440°F to 900°F and transfers its heat to the working fluid through a double-walled tube with mercury in the annular space. This produces steam at 825°F and 620 psi at the rate of 88,700 lb/hr. The low pressure and high temperature characteristics of the sodium in the primary and secondary loops are the outstanding advantages of this type reactor.

—from "Power Engineering," February, 1958

BOOK REVIEWS AND NOTICES

SMALL SEAGOING CRAFT AND VESSELS FOR INLAND NAVIGATION

By
Ir. A. Roorda and Ir. E. M. Neuerburg

Published in 1957 by
The Technical Publishing Company
Haarlem-Holland

560 pages Price 175 Dutch Guilders

Reviewed by
Jack G. Gilmore, Naval Architect,
Bureau of Ships, U. S. Navy Dept.

This book is Volume V of a seven volume series entitled "Ships and Marine Engines," now being written and published in Holland. It is the fourth of the series to be published and the first of the English edition.

In the author's own words, the subject volume "intends to give a treatise on the work, the design and the construction of small sea-going ships and inland vessels which are generally built in small or medium-sized yards." It is a book more of fact than theory. It describes and illustrates vessels in service throughout the world. A large majority of the vessels covered are, quite naturally, of European design and construction.

The book is well-written, well-illustrated (over 500 photographs, maps, plans and tables), comprehensive and is an excellent supplement to the American publications on this subject.

The volume consists of fifteen chapters. In chapter one the various types of inland waters are described. Some types are common to all countries, some to only a few. Those discussed are canals, free rivers, canalized rivers, river mouths, harbors, sea shallows, bays, lakes, lagoons and lower river courses with tidal currents. As pointed out by the author, the various types of waters make different demands on the design of a ship as far as her dimensions, hull-form, seaworthiness, speed, maneuverability and equipment are concerned.

Chapter two describes some particular waterways and the vessels navigating them. Included are the Dutch inland waters, the Belgian and French waterways, rivers and canals in Great Britain, German waterways (particularly the Rhine), the Danube and other waterways in Eastern Europe, inland waterways in the U.S.S.R., and those in North America and other countries outside Europe. With the discussion of each waterway the author has included a general description of the vessels designed especially for each, considering such characteristics as currents, rapids, shallows, locks, etc. An example is the chain (or cable) boat used on the Rhone for towing upstream through rapids, whereby the boat hauls in on a chain lying on the river bottom or a wire rope attached to a fixed point ashore.

Chapter three is entitled "Dumb Barges for Inland Navigation." In it the author presents a comprehensive review of the many types of dumb (non-self-propelled) barges in use throughout the world. Some of the various types described and illustrated are large river and canal barges in Europe (e.g., the Danube-barges and the Rhine-barges), barges navigating narrow canals such as the Franco-Belgian Spits-barge and the English Regent-Canal barges, river lighters for undeveloped waterways, American and European harbor lighters and so-called factory-barges ("the cheapest vessels afloat"). To illustrate the differences in hull form demanded by the different waterways, the contrast between the large barges used on the Rhine and those used on the Danube and Rhone rivers, which have strong currents and rapids, is shown. Also included are the lines of some relatively modern, large river barges in use in Soviet Russia. It is interesting to note that the way in which the flotillas of Russian barges are formed is more American than European, that is, without any space allowed between the barges in longitudinal and transverse directions. Also of interest is the design feature found on many European

barges (particularly the Rhine-barges) called a "herften." This is an enclosed space in the middle or at the ends of a hatchway, extending down below the level of the deck, or even to the bottom of the vessel. This space is used for a pump or winch motor, berthing, stores or simply to provide transverse strength. It is apparent from the plans shown that riveted barge construction is still prevalent in Europe.

Chapter four deals with self-propelled boats for inland navigation. It gives a general description of the various types in use and their systems of propulsion. With the description are lines plans, general arrangement and construction plans for a boat typical of each type. Some of the types described are motor cargo boats for broad, deep inland waters, for narrow canals, for large, navigable rivers and canals in Europe, for large rivers with shallows and rapids, and for inland waterways outside Europe, such as the Congo River system. The majority of the vessels depicted are of European design. Typical of many are the vertical stem and bow frames. As the author points out, raked stems and flaring frames are not suitable for these boats in view of frequent moorings head-on against quays and of entering locks. One system of hull framing shown, rarely seen in American designs, is that of frames running alternately on starboard and port sides, from the deck to the turn of the bilge on the other side.

Cargo vessels for the coasting trade are discussed in chapter five. The author reviews the development of the Dutch and British Coasting trade and the evolution of the European coaster. A general description of these vessels is well illustrated with details of hull construction, propelling machinery, auxiliaries, etc. The various types, their economics, hold capacity, register tonnage, freeboard and stability are discussed in turn. Complemeting the general description are plans and particulars of several typical coasters.

Chapter six concerns sea-going riverships. The author defines these as a special type standing between the sea-going vessel and the river cargo boat. Included is a discussion of the special properties of a sea-going rivership and a comparison with inland vessels and coasters. As typical of these sea-going riverships, the author describes several vessels designed for service on the Rhine, the Danube, the Black Sea and the Mediterranean. As pointed out, the sea-going rivership, from a technical and nautical point of view, is a compromise with many defects. From an economical point of view, the sea-going rivership may or may not be a good proposition, depending on circumstances.

In Chapter seven tankers for coastal and inland navigatiton carrying oil in bulk are described and illustrated. The first part of the chapter is devoted to the rules and regulations concerning the construction, general arrangement and equipment of tank vessels. International as well as European regulations are discussed. The remainder of the chapter is devoted to the various types of tankers, their design, construction, arrangement and propulsion. Also covered are pumps, piping systems, gas-freeing systems, fire-extinguishing systems, tank heating and tank cleaning systems. Typical of the illustrations included are those of a Rhine motor-tanker and a Thames motor-tanker.

Chapter eight continues with passenger ships for coastal and inland navigation. As in the previous chapter, the first section is devoted to rules and regulations, as applying to passenger ships. Such items as subdivision, freeboard and life-saving equipment are discussed. The latter section of the chapter concerns the design and construction of various types of passenger vessels. Stability being of greater importance in passenger vessels, more consideration has been given it than in previous chapters on other vessels. The chapter is well illustrated with plans of passenger vessels ranging in size from 50 feet to 226 feet.

Chapter nine is devoted to ferries, beginning with a description of the various ways of crossing, berthing and loading. The systems of propulsion are described, the special hull forms, principal dimensions, general arrangement and construction. The various types of ferries are considered in turn; side-loading ferries, head and stern-loading ferries, double-ended ferries, towed ferries, cable ferries or floating bridges and other special types. Rules concerning the number of passengers and/or vehicles carried, freeboard, safety means and life-saving appliances are discussed. Also included are descriptions and illustrations of the special arrangements on board and ashore, such as turntables, buffers, vertically adjustable car decks, loading and discharging flaps, and the various types of landing stages, ramps, pontoons and mooring gear.

Chapter ten is entitled "Tug Boats for Inland, Coastal and Sea-going Service." In it the author deals with every phase of tug boat design, construction and operation. It is a very comprehensive review containing descriptions, plans and photographs of every type of tow and tug boats, from early side-wheelers to the most modern sea-going tugs. For convenience, the author has subdivided his discussion of types into the following groups: Tugs for deep inland waters; shallow-draft river tugs; sea going tugs for long voyages; coastal tugs; harbor tugs; and towing launches. Each group is discussed separately. Some of the features of tug boat design and operation discussed in this chapter are tug screw propellers, controllable pitch propellers, Kort nozzles, Voith-Schneider propellers, side and stern wheel propulsion, tunneled-stern tugs, engine installations, hull form, scantlings, towing arrangements, salvage and fire fighting equipment, wire rope vs. manila vs. nylon hawsers, automatic towing equipment, stability and seaworthiness, arrange-

ments, construction, steering and handling, and special towing operations. In the section on tug boat design the author has taken some hypothetical service requirements and worked through the preliminary design calculations. Included are tables of design data, compiled by the author, for the convenience of the tug boat designer.

Of interest to the tug designer is the author's discussion of steam vs. diesel power for tugs. He notes that for boats between 100 and 450 IHP the steam tug is still in the majority in Europe but is rapidly losing ground. He also states that in Europe, "of late, electric welding has been making considerable headway in tug construction but the shell plating is, in general, still riveted." Throughout the volume the author, when referring to American designs in his descriptions of the various types of vessels, frequently uses the phrase "typically American." The author's connotation of this phrase is not clearly evident from his discussion, but one inference may be that he means welded construction and diesel powered as opposed to riveted construction and steam powered.

In chapter eleven the author describes and illustrates the various types of ice-breaking vessels, first the ice-breaking tugs and harbor ice-breakers and second the sea-going ice-breakers. The first type is considered as having one of three different hull forms; a true ice-breaker form, a tug of the Hamburg type, or an intermediate form. The two types of sea-going ice-breakers are described as the European type and the American type, the latter being characterized by its bow-propeller, or fore-screw, and specially designed fore-body. In his discussion of these two types, the author covers briefly their hull form, arrangement, propulsion (steam vs. diesel power), construction, steering gear, pumping installations for trimming and heeling and other features peculiar to each. The latter part of the chapter is devoted to the preliminary design of a typical ice-breaker. As in the other chapters, the author has included tables containing data which he has compiled and feels may be helpful in working out a design.

Chapter twelve is devoted to sea-going fishing vessels. The description, plans and illustrations are extensive. Each type of vessel is discussed with respect to service, seaworthiness and stability, form, construction, power and equipment. The methods of fishing described by the author are herring fishing with drift nets, long line fishing, line fishing by hand, trawl fishing and seine-net fishing. The types of vessels used with each of these methods are discussed in turn—loggers and drifters, long liners, hand liners, trawlers preserving the fish in ice, trawlers freezing their catch on board, trawlers preserving their catch in salt, seiners and small boats for miscellaneous inshore fishing. One section is devoted to American fishing vessels; purse-seiners, tuna clippers, shrimp trawlers, trollers and others. Descriptions of Japanese and Russian vessels are also given. In addition to the fishing vessels, the author has included plans and descriptions of some motor vessels designed specifically to freeze and transport fish.

Chapter thirteen describes barges for dredging work. Some of the various barge types described and illustrated are elevator barges, hopper barges (self-discharging barges with bottom doors), decked or pontoon barges, tipping or tumbler barges (with sloping decks) and self-propelled hopper barges. Only a few paragraphs are devoted to American hopper barges since their use in dredging operations is less frequent than in Europe, such work being done largely by floating pipe lines.

Chapter fourteen is devoted to resistance and powering of ships and screw-propeller design. To quote the author it is "an endeavor to collect from books and publications a set of data and simple calculations most suitable for direct practical use, for the convenience of those readers not in a position to make an extensive study of the subject." The chapter consists of two sections, one entitled "Deep Water Resistance and Powering of Vessels" and the other "Resistance and Powering of Vessels Employed in Navigating Restricted Waterways." In both sections the author has included examples of determining resistance, propeller size and power requirements. Extra resistances are discussed, such as tow rope resistance. Other influences on resistance covered are roughness of canal sections, unevenness of river-bottoms, fall or inclinations of the water level, and current. Also discussed is the influence of the propeller race of a tug on the towed vessel and the influence of the number of and the distance between barges in a tow on the total resistance. Although, as the author states, most of the information presented is available in other publications, the collection of curves, tables and other data is convenient, particularly in preliminary calculations.

Chapter fifteen, the concluding chapter, is entitled "Measurement of River and Canal Vessels." Written by Ir. E. M. Neuerburg, a Dutch authority in this field, it gives a brief history of the measurement rules in use in Europe, beginning with the Convention of Brussels in 1898. The present system of measurement in Europe is described, with natural emphasis on the rules in use in the Netherlands.

RIGGING, EQUIPMENT AND OUTFIT OF SEAGOING SHIPS—PART I

By Ing. J. P. de Haan

Published in 1957 by
The Technical Publishing Company H. Stam
Haarlem, Holland

469 pages 145 Dutch Guilders

Reviewed by
L. W. Ferris

Ship Design Division, Bureau of Ships

There is an ambitious program underway in the Netherlands which will ultimately result in a shelf of books dealing with the various aspects of ship design and construction. In outline, the series will cover the following subjects:

I Theoretical Shipbuilding

A. Ship Calculations

B. Stability and Trim

*II Resistance, Propulsion and Steering of Ships

III Practical Shipbuilding

*A. Construction of Ships

B. Rigging, Equipment and Outfit—Part I and Part II

C. Building of Ships and Layout of Shipbuilding Yards

*IV The Design of Merchant Ships

†*V Small Seagoing Craft and Vessels for Inland Navigation

VI Floating Dredging Material

VII Marine Engines and Marine Engine Installations

A. Marine Diesel Engines

B. Boilers, Steam Reciprocating Engines and Turbines

C. Marine Engine Installations

Books have already been published for those subjects which are marked with an asterisk.

Now a new member of the series is offered to the public. It is Part 1 of IIIB in the outline, and is entitled "Rigging, Equipment and Outfit of Seagoing Ships." The author is Ing. J. P. de Haan, Manager of the Walton-Fijenoord Engineering and Slipway Company, Schiedam, Holland. It is a large book, 469 pages, profusely illustrated.

The best way to characterize this book is to say that it is very comprehensive for the field that it covers. So far as known, no other reference approaches it for detailed descriptions, explanations and illustrations.

The book is, of course, written in English, although it is based on Dutch commercial shipbuilding practice. The numerous excellent drawings which illustrate the text are dimensioned in the metric system. It should be mentioned that a few of the gadgets which are shown are identified by different names than those used in the U. S. Navy, but the illustrations are so complete that there should be no confusion.

Chapters in the book are designated as A through N and cover the following subjects:

A. Rigging (including ropes, fittings, masts, winches)

B. Anchors, Chains, Windlasses, Hawse Pipes, Hawsers and Warps

C. Bollards, Fairleads and Mooring

D. Pipe Railing

E. Ladders, Accommodation Ladders

F. Awnings, Tarpaulins, Battening down Hatches

G. Sundries (including illumination, stages, sounding rods)

H. Side Lights, Fixed Lights, Windows

J. Boats and Boat Chocks

K. Davits and Boat Winches

L. Life Saving and Safety Appliances

M. Nautical Equipment (including compasses, logs, flags)

N. Steering Gear

This book should be most welcome to shipyards and marine design offices as a manual which will assist and facilitate correct detail designing. It should also be useful to ship owners, ship officers and engineering students.

It is planned that the following book (Part 2) will cover joiner work, deck coverings, insulation, refrigerating machinery, pipe work, mechanical outfit, preservation and painting.

† Reviewed in this issue of the JOURNAL.

PRINCIPLES OF ELECTRICAL MEASUREMENTS

By H. Buckingham, M.Sc., Ph.D.
and
E. M. Price, M.Sc. Tech.

Published in 1957 by Philosophical Library Inc.
New York, N. Y.
592 Pages of Text 13 Tables 418 Figures

Reviewed by
Patrick A. O'Riordan, Jr.

Ship Design Division, Bureau of Ships

The purpose of this book is both to provide a knowledge of the principles employed in making electrical measurements and also to explain the methods of applying these principles. The subject matter covers the academic requirements of degree students of electrical engineering and those studying for higher national certificates or diplomas in England.

Since most electrical engineers make their first acquaintance with electrical measurements through the medium of indicating instruments, the authors very wisely chose this topic as their starting point. The first chapter deals with the general construction, torque equations and operating details of indicating instruments. These instruments are grouped in the following maner: (a) those that are based upon the interaction of currents and magnetic fields, some of which include permanent-magnet moving coil, moving iron, electrodynamic and induction type meters; (b) those that are based upon the forces produced by applied potential differences to oppositely charged plates, known as electrostatic type meters; (c) those that are based upon the heating effect which is proportional to the current squared, known as thermal type meters. Included in this chapter is a brief discussion of frequency and power factor meters.

The second chapter treats the usual methods of measuring current, voltage, power and resistance. A discussion of errors in using indicating instruments is given and includes the effects due to temperature changes, circuit placement of instruments, frequency changes, stray magnetic fields and harmonics. The two-wattmeter method of measuring 3-phase power is presented without offering some means of determining whether a wattmeter reading should be taken positive or negative. This is an oversight since it is essential in the two-wattmeter method that the proper sign be given the wattmeter readings and that the sum be taken algebraically.

Alternating Current and Direct Current Potentiometer measurements, the subject of chapter three, leads to a consideration of systems of units and standards in chapter four. This chapter presents a development of and the relationship between each of the following systems: The Electrostatic-e.s.u., Electromagnetic-e.m.u., Practical-c.g.s. and the Rationalized-m.k.s. system of units. Tables are given showing the correct relationships. The treatment of standards of measurement includes standards for resistance, potential difference, inductance and capacitance. A method of calculating the maximum systematic error in the final result of an electrical measurement is also included.

This is followed by four chapters dealing with (1) bridge methods, (2) oscillations and vibrations which contains an excellent treatment on the theory, construction and uses of the Cathode Ray Oscillograph, (3) methods using thermionic valves or tubes, and (4) resonance and heterodyne methods used to measure frequency, inductance and capacitance from 20KC to 10MC.

The chapter on power system measurements gives an interesting presentation of symmetrical components and methods of measuring the component currents and voltages. Location of cable faults is discussed with a brief reference to pulsing methods used for fault location in high frequency cables. Chapter 10 devotes itself to integrating meters and particularly the induction-type of energy meter for the authors state that the metering of alternating current circuits is now much more important than that of direct current systems.

The next two chapters deal with topics that are usually found in a volume devoted to electrical measurements, instrument transformers and magnetic measurements. The final chapter on the electrical measurements of non-electrical quantities has been included in an attempt to illustrate some of the techniques used in this class of measurement which is becoming increasingly more important every day.

The rationalized m.k.s. system has been used throughout the book. However, comparisons are made at certain points by enclosing in square brackets alternative formula using the c.g.s. system. This is done for the convenience of readers accustomed to the older systems. Accounts of electrostatic and electromagnetic theory and of circuit theory have been omitted. This omission has been compensated for by a more extensive treatment of resonance, heterodyne, tube and oscillographic methods than are found in most books dealing with this subject.

This book is sufficiently comprehensive to be a very useful reference source to experienced engineers requiring information on electrical measurements.

BOOKS RECEIVED

"Containerization in Maritime Transportation of General Cargo—A Partial Bibliography," Publication 558, National Academy of Sciences, National Research Council, 2101 Constitution Avenue, Washington 25, D. C. Prepared by The Maritime Cargo Transportation Conference, November 30, 1957.

"Naval Architecture of Small Craft," by D. Phillips-Birt; published in 1957 by Philosophical Library, Inc., 15 East 40th Street, New York 16, N. Y.; 351 pages, $15.00.

"The Radio Amateur's Handbook"—35th edition, published in 1958 by American Radio Relay League, Inc., West Hartford 7, Connecticut; 746 pages, $3.50 (United States), $4.00 (U. S. Possessions and Canada), $4.50 (elsewhere).

"ANACONDA," by Isaac F. Marcosson. Published in 1957 by Dodd, Mead & Company, Inc., New York, N. Y.; 370 pages.

"Radio-isotopes—A New Tool for Industry," by Sidney Jefferson; Published in 1958 by Philosophical Library, Inc., 15 East Fortieth Street, New York 16, N. Y.; 110 pages; $4.75.

CHANGES IN MEMBERSHIP

ADDITIONS TO MEMBERSHIP

The Society is very much pleased to record the addition of the following to its membership since the publication of the February, 1958, JOURNAL:

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It is our sad duty to report the death of the following members reported since the publication of the February, 1958, Journal:

Davidson, Kenneth S. M., Civil Member
Mayville, Armand, Naval Member
Williams, Robert P., Jr., Civil Member

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6. *Include on a separate page a short biographical sketch(es) of the author(s).* 50 to 100 words for each author is desired.

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